

Report of
A series of workshops on the design and construction of
RRR GRS structures for India High-speed Rail

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International Association of RRR Construction System	Takuya Kosaka
JICA Long-Term Expert	
(Currently with Japan International Consultants for Transportation)	K o j i T a k a n o
Japan International Consultants for Transportation	
(Currently with East Japan Railway Company)	V u N h a t L i n h
Railway Technical Research Institute	Susumu Nakajima
Professor Emeritus, University of Tokyo and Tokyo University of Science	Fumio Tatsuoka
Professor, University of Tokyo	Kenji Watanabe
Japan Railway Construction, Transport and Technology Agency	Shinichi Tamai

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1. Introduction

The Mumbai–Ahmedabad High-Speed Rail (MAHSR), spanning approximately 508 km along the western coast of the Indian subcontinent, is being constructed by the National High-Speed Rail Corporation Limited (NHSRCL) utilizing Japan’s Shinkansen system. To minimize the area required for land acquisition, most of the route is elevated. The structural composition comprises 91.6% viaducts, 1.9% bridges, 5.2% tunnels, and 1.3% other earthworks.

The design of civil structures was formulated under a scheme whereby the JICC consortium (Japan International Consultants for Transportation, Nippon Koei, and Oriental Consultants Global) prepared the designs based on Japanese standards with Technical Assistance under JICA’s Loan Account. These designs, “Recommended” by the Committee for the General Consultancy (Excluding Supervision) of MAHSR established by JICA, were subsequently “Adopted” by NHSRCL.

In this project, reinforced earth embankments using Japanese-developed RRR methods—RRR-A (cement based reinforced soil abutments in **Fig1(a)**) and RRR-B (reinforced earth retaining walls in **Fig1(b)**)—are constructed mainly at transition zones between tunnels and viaducts, and at approach lines linking the main elevated track to ground-level depots. As shown in **Table 1**, these methods are applied at 28 locations, with a total length of approximately 3 km.

Table 1: Implementation Length of the RRR-B Method in MAHSR

Package	C3	C4	D1
Contractor	L&T	L&T	MG Contractor
Nos. of locations	25	2	1
Total length	2,479m	38m	425m

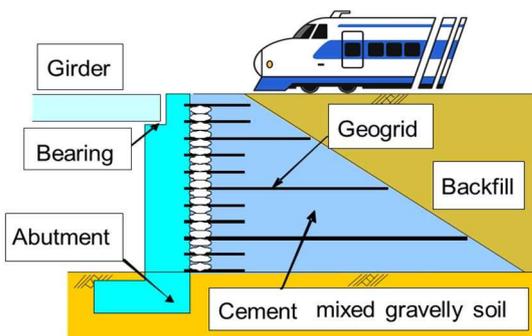


Fig.1(a) Conceptual figure of RRR-A Construction Method (Cement-improved Reinforced-soil Abutment)

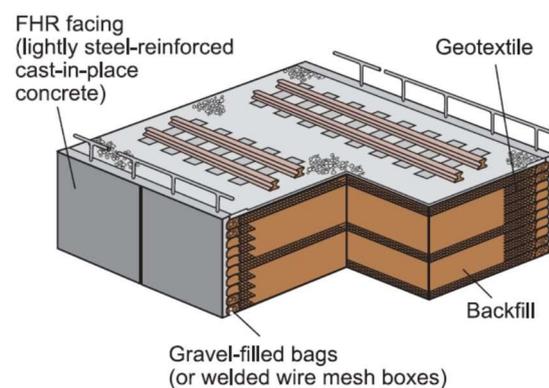


Fig.1(b) Conceptual figure of RRR-B Construction Method (Reinforced-soil Retaining Wall)

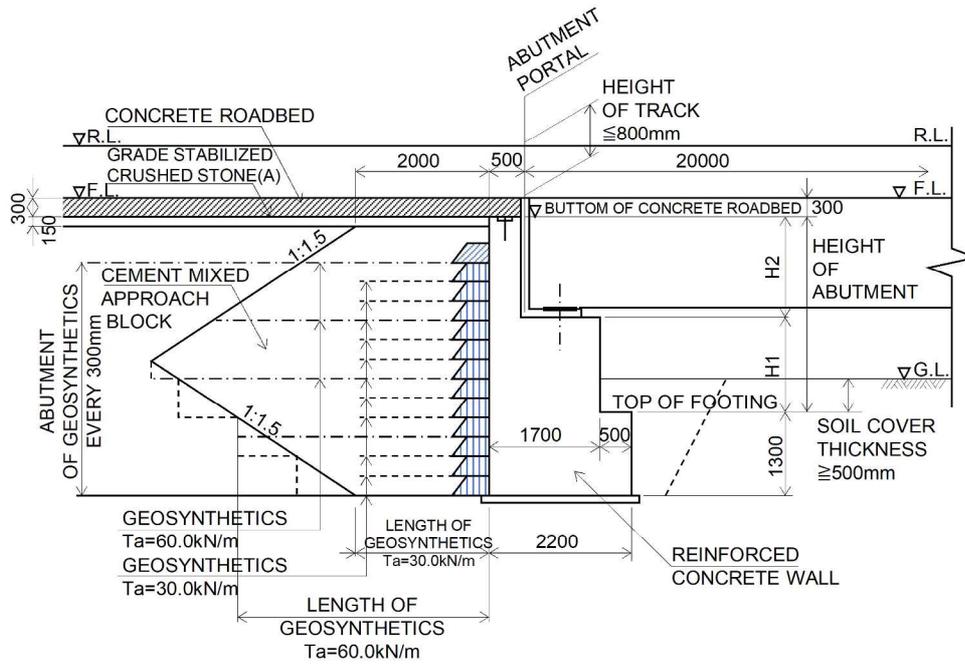
2.Preparation of Standard Design Drawings and Creation of Construction Drawings Using the Finalized Drawing Manual

Although India has extensive experience with conventional reinforced earth embankments, the RRR method is being introduced for the first time ever. Therefore, two aspects are crucial: (i) stable supply of geotextiles with quality equivalent to Japan, and (ii) thorough promotion of understanding in design and construction. A survey focusing on IGS-registered Indian manufacturers was conducted; through consultations, site visits, and prototyping, two highly capable manufacturers possessing equivalent knitting equipment and resin-coating capability were shortlisted. Prototype geotextiles using Japanese yarn achieved the required performance, leading to the policy of procuring yarn from Japan and manufacturing geotextiles domestically in India. Questions concerning design and construction have been progressively addressed through workshops and related initiatives.

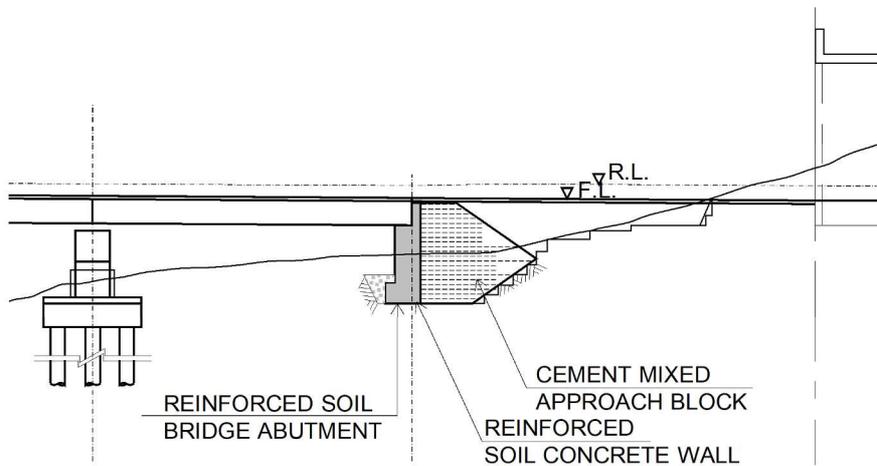
In this project, the civil packages were based on the FIDIC Yellow Book as the contract conditions; however, given reliance on Japanese standards, owner-provided Standard Design (including reinforcement drawings) were supplied for superstructure, substructure, and foundations to mitigate design errors due to insufficient contractor understanding. For reinforced-soil abutments and reinforced earth retaining walls (total length ~3 km), Standard Design Drawings (approx. 180 sheets) were prepared with parameters such as structure height, double/quadruple track, and with/without OHE (see **Table 2**). Contractors select appropriate Standard Design Drawings (**Fig2(a)**) after site review and, following the Drawing Finalization Manual (DFM) included in the contract documents, adjust dimensions to produce Construction Design Drawings (**Fig2(b)**) suited to site conditions. Bearing capacity of support ground is verified through geotechnical investigation, soil tests, and plate load tests; if the required ultimate bearing capacity is not achieved, ground improvement shall be performed as per the DFM flowchart.

Table 2: Types of Standard Designs for RRR-A (Cement-Treated Reinforced Soil Abutments) and RRR-B (Reinforced Earth Retaining Walls)

Type	Condition	Standard Height H	Applicable Range
RRR-A (Cement-Treated Reinforced Soil Abutments)	Double track	H=3.0 / 6.0 / 9.0 / 12.0 m	2.0 m ≤ H ≤ 12.0 m (stepwise)
	Quadruple track	H=4.0 / 8.0 m	2.0 m ≤ H ≤ 8.0 m (stepwise)
RRR-B (Reinforced Earth Retaining Walls)	Double track, without OHE poles	H=4.0 / 8.0 / 12.0 m	1.6 m ≤ H ≤ 12.0 m (stepwise)
	Double track, with OHE poles	H=4.0 / 8.0 / 12.0 m	3.0 m ≤ H ≤ 12.0 m (stepwise)
	Quadruple track, without OHE poles	H=4.0 / 8.0 / 12.0 m	1.6 m ≤ H ≤ 12.0 m (stepwise)
	Quadruple track, with OHE poles	H=4.0 / 8.0 / 12.0 m	3.0 m ≤ H ≤ 12.0 m (stepwise)



**Fig.2(a) Standard Design Drawing Example
(RRR-A Construction Method)**



**Fig.2(b) Construction Design Drawing Example
based on the Finalized Drawing Manual
(Overview General drawing)**

3. Workshop Implementation

3.1 Overall View

It had been agreed between Japan and India that construction supervision would be directly commissioned to JICC, the design consortium, and that certain complex civil packages would be led by Japanese firms to ensure quality. However, due to strong requests from the Indian side and difficulties for Japanese firms to bid during the COVID-19 period, civil packages and construction supervision were opened to Indian contractors and consultants. Consequently, Japanese involvement in assuring construction quality of structures designed under Japanese standards became challenging. JICA long-term expert Yoshihiro Kumamoto and the author (Koji Takano) strongly encouraged NHRCL to hold regular workshops aimed at ensuring the intended quality envisaged at the design stage.

3.2 Workshop on the RRR Construction Method

In May 2023, during the first workshop, Dr. Takashi Tarumi, Fellow of the Railway Technical Research Institute and then Chairperson of the Committee for the General Consultancy (Excluding Supervision) of Mumbai-Ahmedabad High Speed Railway Project, participated and delivered a closing remark presentation expressing strong concerns and a sense of urgency regarding quality assurance for reinforced earth structures in the MAHSR project. Subsequently, in February 2024, Dr. Tarumi issued a letter to NHRCL conveying his apprehensions about ensuring quality in reinforced earth construction and indicating the willingness of the RRR-I Association to provide technical support. This initiative fostered momentum for technical exchange on reinforced earth structures. In March 2024, a webinar organized and hosted by the aforementioned JICA-long-term experts, featuring the RRR-I Association, was conducted for NHRCL, contractors, and construction supervision engineers, focusing on critical considerations during construction (shown in 4.1). This webinar served as a catalyst for selecting reinforced earth structures as the theme for the third (shown in 4.2) and fourth (shown in 4.3) workshops, held thereafter (see Table 3).

Table 3: Summary of Workshops (Co-hosted by JICA, NHRCL, ADBI, and JARTS)

No.	Dates	Theme	Venue	Participants	Site Visit
1	May 9–11, 2023	Concrete Structures	NHRCL (Surat)	60 in-person	C4 Surat Station; FSLM & SBS yards; Tapi River Bridge; etc.
2	Feb 19–20, 2024	Welding Technology for Steel Truss Bridges ¹⁾	NHRCL (Delhi)	60 in-person + 80 online	Sarasa Tech Engineering steel bridge fabrication plant
3	Oct 23–24, 2024	Reinforced Earth Structures & Railway Disaster Prevention	NHRCL (Surat)	60 in-person + 120 online	C4 NATM tunnel outlet area (end side)
4	May 19–22, 2025	Reinforced Earth Structures & Japan–India Partnership	RTRI (Kunitachi) & ADBI (Kasumigaseki)	50 in-person + 45 online	RTRI experimental facilities; Hokkaido Shinkansen (Oshamambe area)

(1) Third Workshop

On October 23–24, 2024, a two-day workshop titled *Construction Method and Quality Control of Geosynthetic-Reinforced Soil (GRS) Structure for High-Speed Rail* was convened, focusing on the themes of RRR method and disaster prevention measures for earthwork sections.

The workshop was attended by members of the Committee for the General Consultancy (Excluding Supervision) of Mumbai-Ahmedabad High Speed Railway Project, including Dr. Shinichi Tamai (JR TT), Mr. Satoshi Takisawa (JR East), Dr. Susumu Nakajima (RTRI), and Mr. Hiroyuki Kawanakajima (JR TT), as well as representatives from India such as Dr. G. Venkatappa Rao (IIT Gandhinagar) and others.

As a pre-workshop site visit, an on-site inspection was conducted at the location where the reinforced earth method was being implemented near the exit portal of the sole tunnel in Package C4 (around Ch156 km) (**Photo 1**).

In this method, the integration of concrete and geotextile is of paramount importance. However, during the site visit as part of the workshop, it was observed that the footing concrete for the RRR abutment had already been placed prior to the construction of the reinforced-soil embankment parts, and the installation of reinforcing bars for the RRR abutment walls was underway. This clearly indicated a misinterpretation of the prescribed construction sequence, which we were able to point out directly at the very last possible moment.



Photo 1. On-site Construction Status of RRR-A Method (Cement-Stabilized Reinforced Soil Abutment)

In Session 1 of the seminar, presentations were delivered by five Japanese speakers under the theme *Experience in Japan* (**Table 4(a)**). Session 2, themed *Experience in India*, featured contributions from NHSRCL, academic experts, contractors, and construction supervision engineers (**Table 4(b)**).

Dr. Rao presented key considerations for implementing the RRR method in India, emphasizing the importance of ensuring uniformity of backfill material, meticulous execution of backside drainage works near tunnel portals, and obtaining numerical parameters for ground improvement design through in-situ measurements. Session 3 comprised a highly substantive Q&A session addressing the Japanese presentations from Session 1, resulting in an exceptionally fruitful discussion.

Table 4(a) Session 1 (Session Chair: Koji Takano)

Speaker/Affiliation	Presentation Theme
Dr. Susumu Nakajima RTRI	Outline and matters necessary to achieve sufficient performance of Geosynthetic Reinforced Soil structures for high-speed railway
Dr. Shinichi Tamai JRTT	GRS Structures along Latest SHINKANSEN
Mr. Takuya Kosaka RRR-I Association	Key Construction Procedures for RRR-GRS Retaining Walls and Bridge Abutments
Mr. Itsuki Koshiishi JARTS	Maintenance of Earth Structures and Disaster Prevention
Mr. Satoshi Takizawa JR East	Disaster prevention measures for earth structure sections at JR East

Table 4(b) Session 2 (Session Chair: H. L. Suthar)

Speaker/Affiliation	Presentation Theme
H.L Suthar NHSRCL	Construction method and Quality Control of Geosynthetic-Reinforced Soil (GRS) structure for High-Speed Rail
Dr. G. Venkatappa Rao IIT GN	Indian Experience with Geosynthetic Reinforced Earth Structures: Key Considerations for Adapting Japan's RRR System
Dr G.D. Raju L&T	Construction Method and Quality Control of Geosynthetic Reinforced Earth Structure For High-Speed Rail
Dr. Prashant IIT GN	Research and Development Project on Geosynthetic Reinforced Soil Walls and Abutments for High-Speed Railway Systems
Mr. Narayana TCAP	Reinforced Backfill Retaining Wall at Ch 156

In conventional geosynthetic-reinforced soil structures, Terre Armée wall (discrete concrete panels) and reinforced-soil layers are alternately constructed. In contrast, the RRR method completes the reinforced soil body first and then builds the wall structure. At approximately Ch156 km, the C4 contractor attempted to build up the concrete abutment foundation prior to constructing the reinforced embankment body, contrary to the procedures stipulated in the Technical Specifications (TS) and Standard Design Drawings. This allowed us to instruct the contractor on the correct sequence and provide guidance on the appropriate corrective construction method. By conducting this site inspection before full-scale implementation of the RRR method - the first such application in this project - we were able to address the issue before it escalated.

Throughout the workshop, there was a lively exchange of views on the concept of the reinforced embankment method (including characteristics of geotextiles and handling of cement-treated soil), construction practices (such as settlement control of the supporting ground, compaction methods during backfilling, and frequency of field tests), and Japan's approach to slope disaster prevention (**Photo 2**). These discussions significantly contributed to achieving the workshop's objectives: transferring technology, knowledge, and experience between Japan and India, and fostering a robust network among engineers (**Photo 3**).



Photo 2. Scene from the Third Workshop Seminar



Photo 3. Group Photograph of Participants at the Third Workshop (at NHSRCL, Surat)

(2) Fourth Workshop

To follow up on the Third Workshop held in October 2024, the Fourth Workshop was organized in Japan from May 19 to 22, 2025, with the full cooperation of the Railway Technical Research Institute (RTRI) and the Japan Railway Construction, Transport and Technology Agency (JRTT). The program comprised site visits to RTRI experimental facilities, classroom sessions, an on-site inspection of RRR method applications in the Oshamanbe area of the Hokkaido Shinkansen, and a wrap-up discussion. Sixteen participants from India—including scholars from IIT, representatives of NHSRCL, contractors for Packages C3 and D1, and TCAP construction supervision consultants—were invited to Japan (**Photo 4**).

A key highlight was the opportunity to observe approximately 1.1 km of continuous reinforced soil structures and various configurations of RRR structures, such as reinforced soil abutments and retaining walls, under construction on the Hokkaido Shinkansen. This experience significantly contributed to ensuring construction quality for the first implementation of the RRR method in India (**Photo 5**). On the final day, a Q&A session titled *Key Learnings from the Field Trip with Participants* was moderated by Mr. Nikhil Bugalia of IIT Madras. Questions and observations from the site visit were addressed by RTRI's Dr. Nakajima and other experts. Participants provided highly positive feedback, noting that the timing was ideal given the imminent commencement of full-scale construction in Maharashtra and that the workshop enabled them to understand both the theoretical and practical foundations of the construction method (**Photo 6**).



Photo 4. Scene from the Fourth Workshop Seminar



Photo 5. Site Visit to the Hokkaido Shinkansen Construction Area Implementing the RRR Method



Photo 6. Group Photograph of Participants at the Fourth Workshop (at ADBI, Kasumigaseki)

4. Summary of Webinar and Workshops on the RRR Construction Method

4.1 Webinar (WEB by Indian and Japanese participants), 27 March 2024

The objective of this webinar is explanation and confirmation of the key construction procedures for RRR GRS Retaining Walls and RRR GRS Bridge Abutments for India High-Speed Rail. To this end, the following presentations were made:

- (1) Key construction procedures and their proper execution for successful construction of RRR GRS Retaining Walls and Bridge Abutment (Tatsuoka, F., University of Tokyo and Tokyo University of Science)
 - 1) History, SOA and perspective of RRR Geosynthetic-Reinforced Soil (GRS) Structures for High-Speed Railway (Shinkansen) in Japan, explaining:
 - Structures of RRR GRS Retaining Wall (RW) and GRS Bridge Abutment; and
 - Characteristic features of RRR (Reinforced-Soil Road Structures with Rigid Facing) construction method
 - 2) Explanation of the key construction procedures for RRR GRS structures emphasizing that this time of the construction of RRR GRS structures for High-Speed Rail is the first case of the construction of RRR GRS structures in India, therefore, it is necessary for the related parties, including owners, contractors and consultants, to well confirm all the details of the construction procedures prior to the start of the project
 - 3) Discussions and Q&A to identify the problematic issues to be alleviated
These are summarized in **Appendix I -4**: Discussions with inquiries and responses
- (2) Technical Issues for successful construction of RRR GRS Retaining Walls and RRR GRS Bridge Abutments following TS (Nakajima, S., Railway Technical Research Institute, Japan)
- (3) Image video of RRR GRS Retaining Wall construction procedures (Kosaka, T., Chief Secretariat of RRR-I Association)
 - This video visually explains the construction procedures of RRR GRS structures
 - The video can be obtained from: <https://www.rrr-sys.gr.jp/en/>
- (4) Free discussions and Q & A (interpreted by Ruchi, N., coordinated by Duttine, A.)
 - Discussions including the future plan summarized by Duttine, A. (RRR-I) are shown in **Appendix I -4-1**: Minutes of webinar

4.2 Third Workshop in India with visiting GRS Bridge Abutment at C4-ES2, 21 – 25 October 2024

The objective of this workshop is to exchange knowledge among various stakeholders involved in design, construction, supervision and manufacturing of materials for RRR GRS structures in India as well as Japan. In particular, the discussions that are much more specific than before, based on a visit to a typical construction site of RRR GRS Bridge Abutment. A number of Indian engineers were able to participate in this workshop as it was held in India:

- (1) 23 Oct. 2024, Visiting Vapi, the construction site of the first RRR GRS Bridge Abutment to confirm a couple of construction issues on site

- (2) 24 Oct. 2024, a workshop was held following the agenda (shown in **Appendix II -1**). It was very important and useful that some essential issues about the method and procedures of the construction of RRR GRS Retaining Walls and Bridge Abutments that were much more specific than those made in the first webinar were discussed. The following five key construction points were re-confirmed based on the presentation by Tatsuoka:
 - 1) The use of proper geosynthetic-reinforcement (i.e., geogrid) having:
 - a) a rupture strength and high stiffness that is required for a low deformability and a high stability of RRR GRS structures
 - b) a high durability against high pH because of direct contact with concrete; and
 - c) a high pull-out strength in the backfill and concrete, in addition to a high rupture strength
 - 2) The use of temporary facing units that satisfy the following contradicting requirements:
 - a) flexible enough to accommodate the deformation of the backfill and subsoil caused by the construction of the backfill; and
 - b) strong enough to be stable against the earth pressure and compaction forces during wall construction
 - 3) The use of backfill of high quality; good compaction; and confirmation of high quality of compacted backfill
 - 4) Confirmation of sufficient settlement of the backfill caused by its construction before the construction of RC facing (i.e., staged construction) and sub-soil layers
 - 5) The construction of full-height rigid (FHR) facing by casting-in-place fresh concrete after the end of the settlement of the backfill and sub-soil layers. The FHR facing should be constructed in such that all the geosynthetic-reinforcement layers are firmly connected to the back of the FHR facing

4.3 Forth Workshop in Japan with visiting GRS structures at Oshamanbe for Hokkaido Shinkansen, 19 - 22 May 2025

The objective is to re-confirm the key construction procedures for RRR GRS Retaining Walls and RRR GRS Bridges Abutments for India High-Speed Rail and to identify new issues that would be found by visiting: (a) full-scale models of RRR GRS retaining walls and GRS Integral Bridges at RTRI in Kunitachi City, Tokyo; and (b) a number of RRR GRS Retaining Walls, GRS Bridge Abutments and GRS Integral Bridges under construction at Oshamanbe for Hokkaido Shinkansen.

(1) 19 May 2025: Visiting RTRI at Kunitachi City

- 1) Visiting research facilities related to the design and construction of soil structures which were and being used for the development of RRR GRS structures, followed by visiting to full scale models of RRR GRS Retaining Walls and a pair of RRR GRS Integral Bridges. This was an indispensable opportunity for Indian participants to recognize and understand the history of research performed for the development of RRR GRS structures.
- 2) Workshop at RTRI to reconfirm the key construction procedures for RRR GRS Retaining Walls and RRR GRS Bridges Abutments for India High-Speed Rail. This workshop was very useful for the persons who participated in this series of workshop for the first time.

(2) 21 May 2025, visiting a number of RRR GRS Retaining Walls, GRS Bridge Abutments and GRS Integral Bridges under construction at Oshamanbe, for Hokkaido Shinkansen

This was the first opportunity for a number of the key engineers from India related to the design and construction of India High-Speed Rail to see actual RRR GRS Retaining Walls, RRR GRS Bridge Abutments and GRS Integral Bridges under construction. In particular, they could confirm the details of the construction procedures of geogrid-reinforced backfill and full-height rigid facing. As the RRR GRS structures at Oshamanbe were at the stage immediately before the construction of full-height rigid facing, it was possible to confirm the construction method of vertical wall face of geosynthetic-reinforced backfill and the details of the preparation work for the construction of full-height rigid facing.

(3) 22 May 2025 at ADBI, a wrap-up workshop based on a visit to Oshamanbe

A number of important inquiries were made based on a visit to Oshamanbe. The inquiries made at the site and during this workshop and the responses are summarized in **Appendix III-4**.

5. Conclusion

In June 2025, C3 Contractor (L&T) contacted Dr. Susumu Nakajima, RTRI, requesting on-site construction guidance (for a fee). The Integrated Geotechnology Institute, Limited., which serves as the lead member of the International Association of RRR-I Construction System, plans to provide construction guidance to L&T and TATA. The webinar held in March 2024 and the 3rd and 4th workshops served as catalysts, leading to concrete actions toward technology transfer—a significant achievement.

According to NHSRCL website, as of the end of December 2025, approximately 70% of the 515 km total length between Mumbai and Ahmedabad—specifically 350 km of girder-type viaducts—has been completed. Construction on earthworks will commence in earnest starting this fiscal year. RRR-I Association intends to continue providing design and construction support tailored to site conditions to the extent possible.

The authors anticipate that, in the near future, Shinkansen trains will operate atop the RRR structures. When high-speed rail services are inaugurated in India, the authors would welcome the opportunity to visit the site and reflect on their condition, albeit modest, to the design of earth structures ensuring the safety and reliability of the system.

Acknowledgments

Dr. Susumu Nakajima, Research Director of the Railway Technical Research Institute, led the workshop response from the front lines. We sincerely thank you. Dr. Shinichi Tamai and Mr. Hiroshi Kawanakajima of the Japan Railway Construction, Transport and Technology Agency actively participated in the workshop. We are also deeply grateful to all members of the JRRTT's Hokkaido Bureau for their tremendous assistance during the site visit for the fourth workshop.

Furthermore, during the workshop, Mr. K.E. Seetharam of Asian Development Bank Institute, Mr. Shinji Morimoto of Japan International Cooperation Agency who was then serving as the secretariat, and Mr. Yoshihiro Kumamoto, who was dispatched to India as a former JICA long-term expert, provided tremendous support in coordinating with relevant parties. In addition, we deeply appreciate the invaluable support of Ms. Ryoko Nakano of East Japan Railway Company, Mr. Hajime Yoshida of Japan International Consultants for Transportation Co., Ltd., and numerous other persons concerned. Without their assistance, the workshop's success and the subsequent paid request for on-site construction guidance from L&T would never have been possible.

References

- 1) Minami, Yoshida, Nakano, Fujino : Technical Exchange Between Japan and India for Ensuring Quality in Steel Bridges for India's High-Speed Rail Project, "Bridges and Foundations", July 2025

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I. Webinar [27 March 2024]
(WEB by Indian and Japanese participants)

I-1 Webinar agenda including the list of participants

One day workshop on
Key construction procedures for RRR GRS retaining walls and RRR GRS bridges abutments of
India High Speed Rail

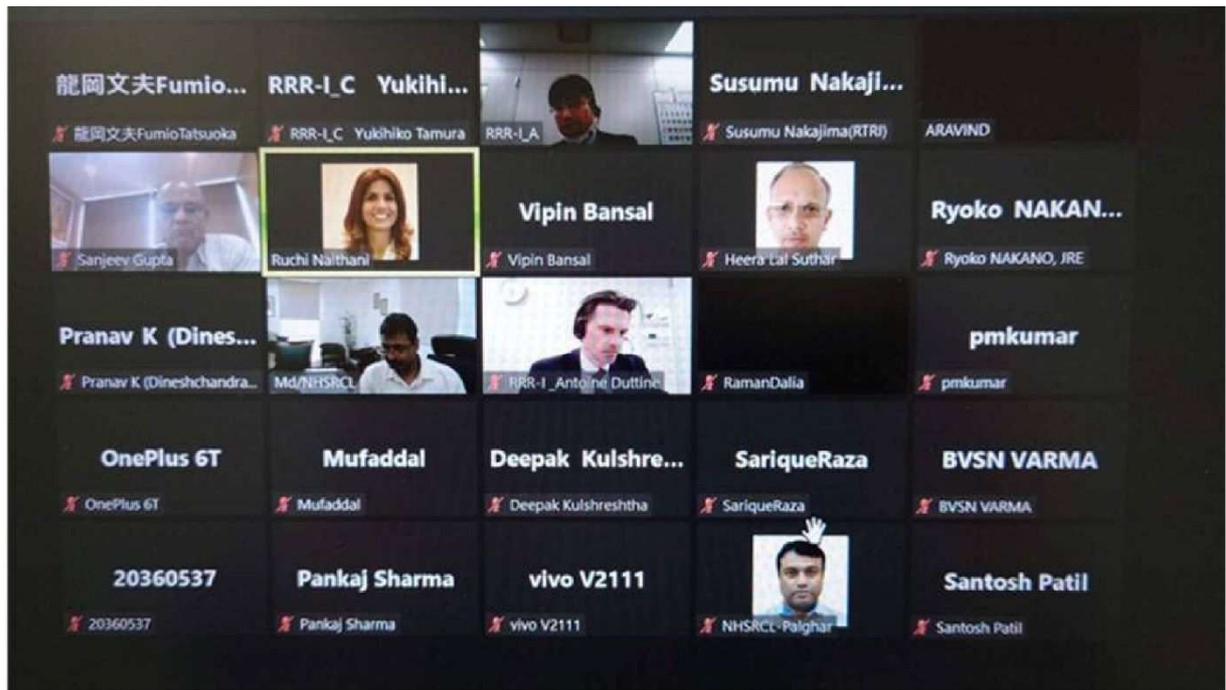
13:00 hrs to 15:00 hrs, IST, March 27th, 2024

- ① Objectives of the WS (Kosaka, T., Chief Secretariat of RRR-I)
- ② Key construction procedures and their proper execution
(Tatsuoka, F., University of Tokyo and RRR-I)
- ③ Explanation of the related parts of Technical Issues
(Nakajima, S., Railway Technical Research Institute, Japan)
- ④ Image video (draft) of RRR GRS Retaining Wall construction procedures
(<https://www.rrr-sys.gr.jp/en/>) (Kosaka, T., Chief Secretariat of RRR-I)
- ⑤ Free discussions and Q & A (interpreted by Ruchi, N. and coordinated by Duttine, A.)
- ⑥ Summary of the discussions and the Future plan (Duttine, A., RRR-I)

List of participants

NO.	Name	Organization	Possition	備考
1	Sanjeev Gupta	NHSRCL	President	
2	H L Suthar	NHSRCL	PED/T&D & DG, HSRIC	
3	Sri Vipin Kumar Bansal	NHSRCL	SrMgr Design	
4	Palghar	NHSRCL		
5	Pranav Kumar	DRA, D-1 Package	VP Technical	
6	Sarique Raza	TCAP (PMC-Civil)	Chief Geotechnical Engineer	
7	Raman Dalia			
8	P M Kumar			
9	Mufaddal			
10	Deepak Kulshreshtha			
11	BVSN Varma			
12	Pankaj Sharma			
13	Santosh Patil			
14	Ruchi Naithani			Interpreter
15	Susumu Nakajima	RTRI	General Manager	Presenter
16	Fumio Tatsuoka	RRR-I Association	Professor emeritus	Presenter
17	Takuya Kosaka	RRR-I Association	Chief secretariat	Presenter
18	Shinji Morimoto	JICA		
19	Yoshihiro Kumamoto	JICA Expert		
20	Koji Takano	JICA Expert		
21	Ryoko Nakano	JRE		
22	Yukihiko Tamura	RRR-I Association		
23	Antoine Duttine	RRR-I Association		
24	Noriaki Ebii	RRR-I Association(YEBISUS)		
25	Hajime Yoshida	JIC		
26	Noriyuki Kurihara	JIC		
27	Vu NHay Linh	JIC		

I-2 Picture of webinar



I-3 PPT presentations

I-3-1 Fumio Tatsuoka (Professor Emeritus, University of Tokyo, Tokyo University of Science)

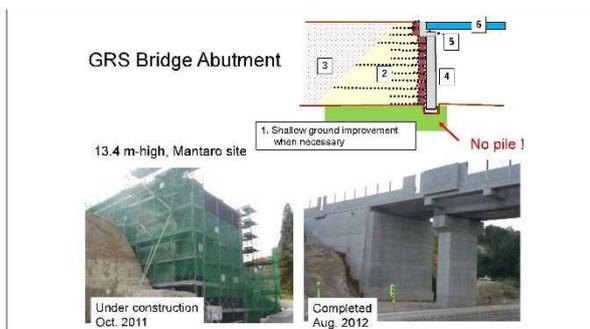
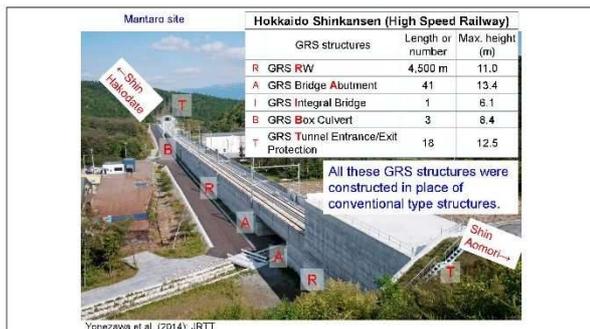
High Speed Rail in India (Mumbai-Ahmedabad: Section C4)

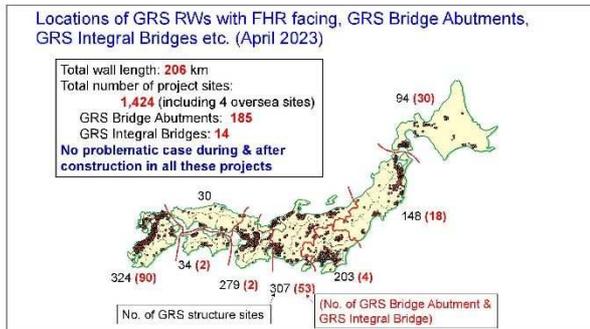
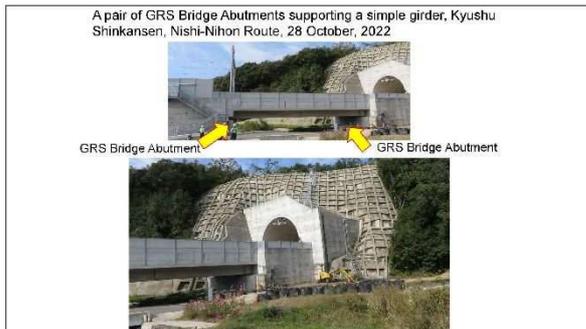
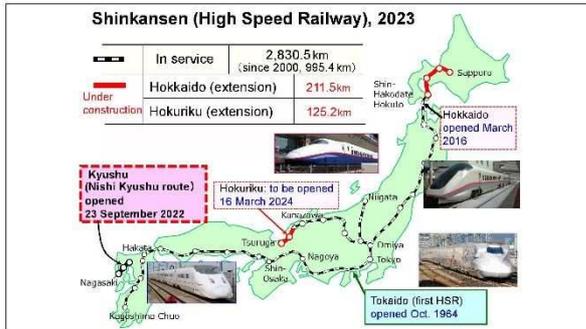
**Key Construction Procedures and Their Proper Execution
for successful construction of
GRS retaining walls and GRS bridge abutments
following TS**

Railway Technical Research Institute, Japan (RTRI)
International Association of RRR Construction System (RRR-I)

Objectives of the workshop 27 March 2024:

- A brief introduction of RRR Geosynthetic-Reinforced Soil (GRS) Structures for High Speed Railway (Shinkansen) in Japan**
 - GRS Retaining Wall (RW); and GRS Bridge Abutment
 - RRR: Reinforced-Soil Road Structures with Rigid Facing**
- Explanation of the key construction procedures for RRR GRS structures**
As the construction of RRR GRS structures for High Speed Rail is the first case in India, it is necessary for the related parties, including contractors, to fully confirm all the details of the construction procedures prior to the start of the project.
- Discussions and Q&A to identify the issues to be alleviate





GRS RW with FHR facing

Re-construction of a gentle slope to a vertical wall for the depot of HSR (Shinkansen) at Biwajima, Nagoya

1991

Key construction procedures for RRR GRS retaining walls (1)

- 1) Leveling pad & projected part of FHR facing
- 2) Fixing the first geogrid layer & a temporary facing unit

* Walled area with mesh : Geogrid

Key construction procedures for RRR GRS retaining walls (2)

- 3) Backfilling & compaction of the first soil layer
- 4) Second layer

Wrapping - Crusher run around of geogrid

Compressor

Key construction procedures for RRR GRS retaining walls (3)

- 5) Backfilling & compaction of the first soil layer
- 6) Completing GRS wall (with FHR facing)

Wrapping - Crusher run around of geogrid

Compressor

Completed backfill, waiting for the end of the deformation of backfill and subsoil

Key construction procedures for RRR GRS retaining walls (3)

- 7) FHR facing by sinking in place concrete
- 8) Completing GRS wall (with FHR facing)

Completed wall, after the construction of FHR facing

Key construction procedures for RRR GRS retaining walls (4)

Detailed steps a) through j), described on the following pages.

- a) Excavation/Leveling of Ground and Facing Foundation
- b) Preparation and cutting/Installation of Geogrid
- c) Arrangement of L-shaped Temporary Facing Unit
- d) Preparation and Spreading of Crushed Stone and Backfill
- e) Compaction of Crusher Run and Backfill
- f) Evaluation of the properties of compacted backfill
- g) Wrapping-Around of Temporary Facing Unit with Geogrid
- h) Finishing of Backfill Construction
- i) Observation of Deformation of Backfill and Subsoil
- j) Construction of full-height RC facing

Repeat

- 9) Backfilling & compaction of the first soil layer
- 10) Completing GRS wall (with FHR facing)

Wrapping - Crusher run around of geogrid

Compressor

Drain hole

Each step of construction procedures (1/8)

- Excavation/Leveling of Ground and Facing Foundation
- Preparation and cutting/Installation of Geogrid
- Arrangement of L-shaped Temporary Facing Unit
- Preparation and Spreading of Crushed Stone and Backfill
- Compaction of Crusher Run and Backfill
- Evaluation of the properties of compacted backfill
- Wrapping Around of Temporary Facing Unit with Geogrid
- Finishing of Backfill Construction
- Observation of Deformation of Backfill and Subsoil
- Construction of full-height RC facing

1) Levelling pad & embedded part of FHR facing



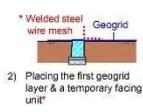

Foundation work

Photo courtesy : TAISEI Co., Ltd.

Each step of construction procedures (2/8)

- Excavation/Leveling of Ground and Facing Foundation
- Preparation and cutting/Installation of Geogrid
- Arrangement of L-shaped Temporary Facing Unit
- Preparation and Spreading of Crushed Stone and Backfill
- Compaction of Crusher Run and Backfill
- Evaluation of the properties of compacted backfill
- Wrapping Around of Temporary Facing Unit with Geogrid
- Finishing of Backfill Construction
- Observation of Deformation of Backfill and Subsoil
- Construction of full-height RC facing

2) Placing the first geogrid layer & a temporary facing unit*



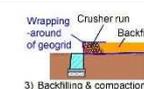

Arrangement of L-shaped temporary facing unit

Photo courtesy : TAISEI Co., Ltd.

Each step of construction procedures (3/8)

- Excavation/Leveling of Ground and Facing Foundation
- Preparation and cutting/Installation of Geogrid
- Arrangement of L-shaped Temporary Facing Unit
- Preparation and Spreading of Crushed Stone and Backfill
- Compaction of Crusher Run and Backfill
- Evaluation of the properties of compacted backfill
- Wrapping Around of Temporary Facing Unit with Geogrid
- Finishing of Backfill Construction
- Observation of Deformation of Backfill and Subsoil
- Construction of full-height RC facing

3) Backfilling & compaction of the first soil layer





Spreading of crushed stone

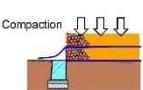
Spreading of backfill

Photo courtesy : TAISEI Co., Ltd.

Each step of construction procedures (4/8)

- Excavation/Leveling of Ground and Facing Foundation
- Preparation and cutting/Installation of Geogrid
- Arrangement of L-shaped Temporary Facing Unit
- Preparation and Spreading of Crushed Stone and Backfill
- Compaction of Crusher Run and Backfill
- Evaluation of the properties of compacted backfill
- Wrapping Around of Temporary Facing Unit with Geogrid
- Finishing of Backfill Construction
- Observation of Deformation of Backfill and Subsoil
- Construction of full-height RC facing

4) Second layer




Compaction work

Photo courtesy : TAISEI Co., Ltd.

Each step of construction procedures (5/8)

- Excavation/Leveling of Ground and Facing Foundation
- Preparation and cutting/Installation of Geogrid
- Arrangement of L-shaped Temporary Facing Unit
- Preparation and Spreading of Crushed Stone and Backfill
- Compaction of Crusher Run and Backfill
- Evaluation of the properties of compacted backfill
- Wrapping Around of Temporary Facing Unit with Geogrid
- Finishing of Backfill Construction
- Observation of Deformation of Backfill and Subsoil
- Construction of full-height RC facing

Plate loading test to evaluate K_{eq}




Density test by the sand cone method

Photo courtesy : TAISEI Co., Ltd.

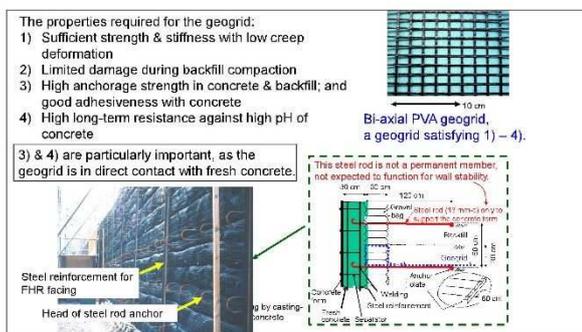
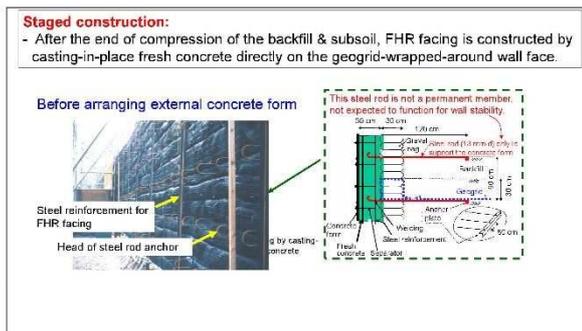
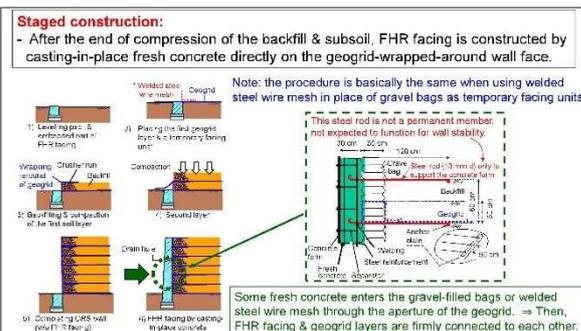
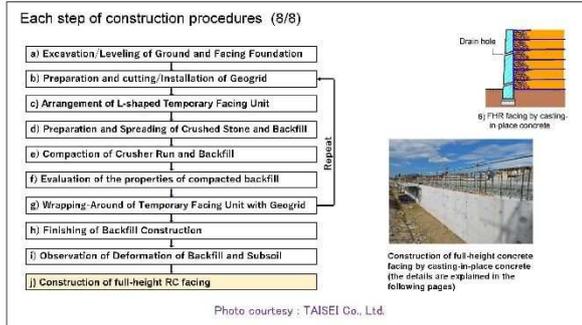
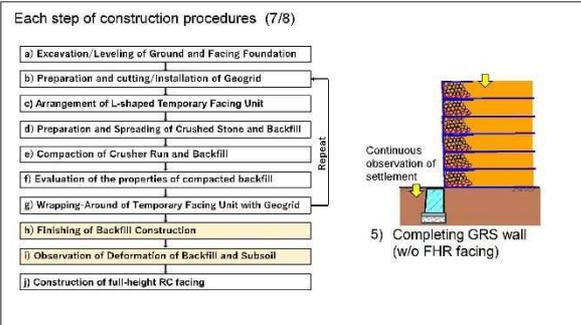
Each step of construction procedures (6/8)

- Excavation/Leveling of Ground and Facing Foundation
- Preparation and cutting/Installation of Geogrid
- Arrangement of L-shaped Temporary Facing Unit
- Preparation and Spreading of Crushed Stone and Backfill
- Compaction of Crusher Run and Backfill
- Evaluation of the properties of compacted backfill
- Wrapping Around of Temporary Facing Unit with Geogrid
- Finishing of Backfill Construction
- Observation of Deformation of Backfill and Subsoil
- Construction of full-height RC facing

Arrangement of geogrid (before wrapping-around of temporary facing unit)



Photo courtesy : TAISEI Co., Ltd.



Field & laboratory tests to confirm high separation strength

Field separation test

Lift up

Gravel-filled block

Geogrid reinforcement

A piece of PFR facing

Test specimen (cut out from 40 cm-thick full-scale FHR facing), hung under 1 g:
⇒ no separation

Laboratory separation test

Specimen after separation

S = separation strength is much higher than "L" stress by the inertia of 1.0 m-thick facing subjected to horizontal acceleration of 1 g"

Separation stress (MPa)

Separation displacement (mm)

Major differences between GRS RW and GRS bridge abutment

GRS RW

1) Longer geogrid at the top; and shorter geogrid at the bottom

2) No cement-mixing of backfill

1) The use of short basic geogrid layers to minimize the excavation when constructed on slope.
Several long geogrid layers at upper levels for high wall stability; and for high stability of surface soil layer (i.e., railway bed).

2) A good compaction is the must, but when compared with GRS bridge abutments, relatively small effects of the settlement of the backfill relative to the facing on the smooth running of train in the direction parallel to the wall face. Loads on the facing are relatively low.

GRS Bridge Abutment

1) Longer geogrid at the bottom

2) a) Cement-mixed backfill of approach block; b) stronger facing/geogrid connection; & c) stronger facing structure, due to severer loads and smaller allowable displacements.

1) To lower the gravity center of approach block for its high stability against overturning about the facing base.
- To avoid cracking in the brittle cement-mixed backfill if compacted on relatively deformable unreinforced backfill.
- For a gradual increase from zero in the thickness of unreinforced backfill in the direction of railway axis (i.e., in the direction perpendicular to the wall face) to achieve a gradual change in the stiffness & settlement in the backfill for smooth train/vehicle running, particularly because continuous RC-slab tracks is used.

Key construction procedures for GRS bridge abutment

The procedures to be exclusively applied to GRS bridge abutments are listed below. More details are explained in Appendix.

The other items than those listed below are basically the same as those for GRS retaining walls.

c/BA) Preparation of Backfill Material for Approach Block

d-1/BA) Mixing of Backfill Material with Cement and Water (including mixing proportion design based on a series of laboratory tests)

d-2/BA) Spreading of Uncement-Mixed Crusher Run and Cement-Mixed Backfill Material

e/BA) Compaction of Uncement-Mixed Crusher Run and Cement-Mixed Backfill Material

GRS bridge abutment

2. Explanation of Key Construction Procedures for RRR GRS structures

2-1. Overview

2-2. Theoretical and practical background for better understanding of the importance of the key construction procedures

2-3. Steps likely to be taken and what RRR-I can do

Appendix: Some details of the key construction procedures
The full details are described in two manuals:
- Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures, RRR Association, p.136
- Manual for the design and construction of RRR GRS Bridge Abutment, Railway Technical Research Institute (RTRI) and Japan Railway Construction, Transport and Technology Agency (JRRTT), November 2020, p.109

There are many reasons for these specific construction procedures. There are a couple of particularly important core construction procedures.

Herein, these are explained.

1) Leveling and embedding of facing

2) Facing the first geogrid layer

3) Backfilling and compaction of the first backfill layer

4) Second layer

5) Completion of GRS wall

6) PFR facing by casting in place concrete

a) Excavation/Leveling of Ground and Facing Foundation

b) Preparation and cutting/Installation of Geogrid

c) Arrangement of L-shaped Temporary Facing Unit

d) Preparation and Spreading of Crushed Stone and Backfill

e) Compaction of Crusher Run and Backfill

f) Evaluation of the properties of compacted backfill

g) Wrapping-Around of Temporary Facing Unit with Geogrid

h) Finishing of Backfill Construction

i) Observation of Deformation of Backfill and Subsoil

j) Construction of full-height RC-facing

Theoretical and practical background for RRR GRS structures

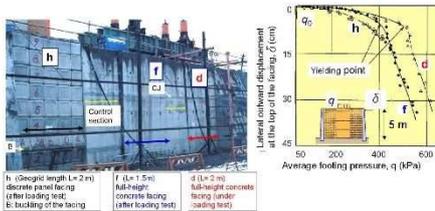
1) Three major advantageous performances

2) Three basic characteristic technologies

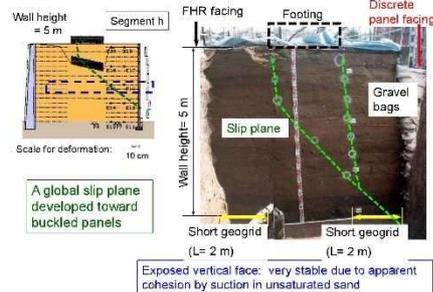
3) Characteristic structural features

4) Five core construction procedures

Segment h (discrete panel facing & geogrid length L= 2 m)
 - the facing buckled, which resulted in the lowest wall stability

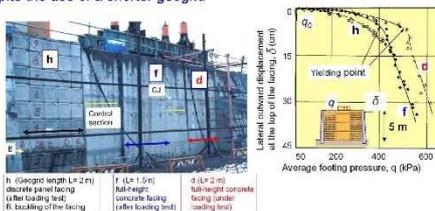


Cross-section of segment h, exposed by excavation



Segment h (discrete panel facing & geogrid length L= 2 m)
 - the facing buckled, which resulted in the lowest wall stability

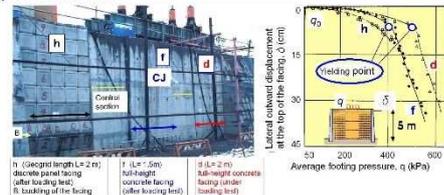
Segment f (FHR facing & L= 1.5 m for a wall height of 5 m);
 - more stable than segment h due to the use of FHR facing, despite the use of a shorter geogrid



Segment d (FHR facing & L= 2 m):

- more stable than segment f (L= 1.5 m) due to a longer geogrid;
 - much more stable than segment h due to the use of FHR facing.

However, segments f & d yielded by the failure at the construction joint CJ in the concrete facing (not steel-reinforced).
 => All the FHR facings of the prototype GRS RWs constructed subsequently are lightly steel-reinforced.



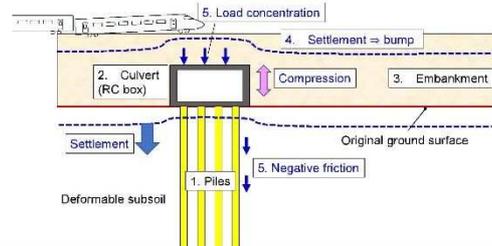
2) Three basic characteristic technologies of RRR GRS structures

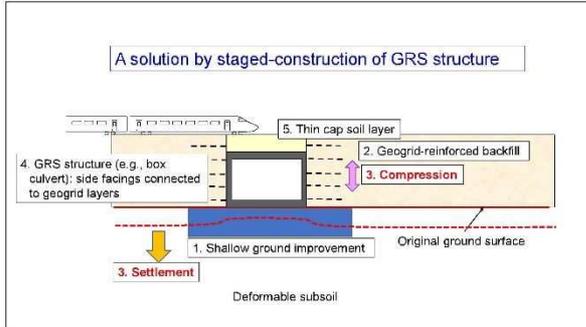
To ensure the advantageous features are:

- (1) Full-height rigid (FHR) facing firmly connected to the geogrid layers, unlike other GRS RW types.
- (2) Staged construction by firstly the construction of reinforced backfill to the full wall height using temporary facing units; then, after the end of the deformation of the backfill and subsoil, the construction of FHR facing by casting in-place fresh concrete directly on the wall face, without occupying large space in front of the wall face.



Several serious problems with the box culvert crossing road/railway embankment on deformable subsoil constructed by the conventional method

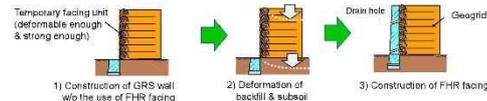




2) Three basic characteristic technologies of RRR GRS structures

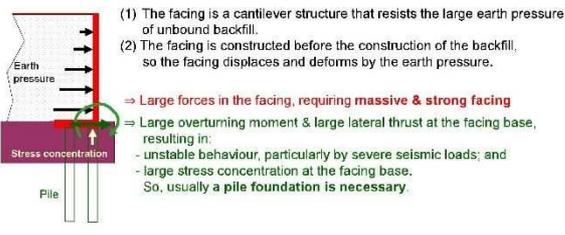
To ensure the advantageous features are:

- (1) **Full-height rigid (FHR) facing** firmly connected to the geogrid layers, unlike other GRS RW types.
- (2) **Staged construction** by firstly the construction of reinforced backfill to the full wall height using temporary facing units; then, after the end of the deformation of the backfill and subsoil, the construction of FHR facing by casting-in-place fresh concrete directly on the wall face, without occupying large space in front of the wall face.
- (3) **Densely arranged geogrid layers having a very high durability against high pH**, as the geogrid is in direct contact with concrete, and a small vertical spacing (i.e., 30 cm) to enhance high performance as a composite.

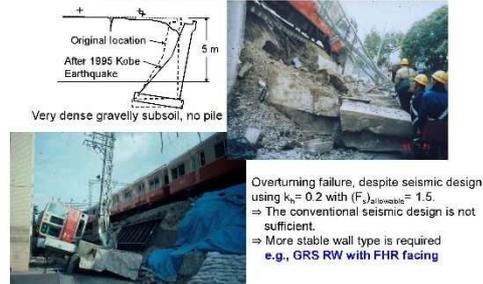


3) Characteristic structural features of RRR GRS structures, in comparison with conventional retaining walls

Conventional retaining walls



Collapse of gravity wall (i.e., cantilever RW) Ishiyagawa, 1995 Kobe Earthquake



RRR GRS retaining walls and RRR GRS bridge abutments

- (1) The backfill is stabilized by **geogrid-reinforcing**.
- (2) FHR facing is constructed after the deformation of the backfill and the subsoil by the construction of the backfill has taken place (**the staged-construction**). Then, the FHR facing does not deform nor displace by the earth pressure from the backfill.
- (3) The FHR facing is "a continuous beam supported by many reinforcement layers at a small span (i.e., 30 cm)".



Conventional cantilever RW

Often, over-turning failure by scouring below the wall, quickly followed by the global collapse of embankment, resulting in the close of road & railway

RRR GRS-RW with FHR facing

Substantially better performance; i.e.,

- 1) No over-turning failure of FHR facing by scouring;
- 2) so, the embankment can survive not closing road & railway.

Collapse of gravity-type seawall for a length of 1.5 km by ocean waves during a storm (Typhoon No. 9), 8 Sept. 2007 National Road No. 1, southwest of Tokyo

In front of the wall, about 100 m-wide sand beach disappeared due to erosion by coastal current during the last 60 years since the completion of this road, which resulted in frequent direct attack of storm ocean waves to the wall.

Before collapse:

(by the courtesy of Ministry of LITT, Japan)

Restoration to GRS RW with FHR facing

10 March 2010

After restoration

13 years after restoration to GRS RW with FHR facing

26 Oct. 2023

- have survived frequent attacks of storm ocean wave, on average twice a year

4) Five core construction procedures of RRR GRS structures -1/2

- the minimum to avoid serious troubles:

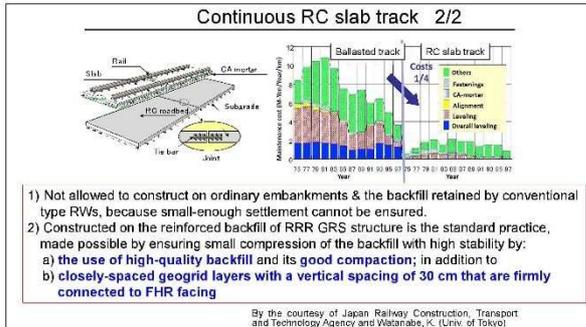
- (1) The use of geogrid having a very high durability against high pH (because of direct contact with concrete) and a high pull-out strength in the backfill and the concrete.
- (2) The use of temporary facing units that satisfy contradicting requirements:
 - a) flexible enough to accommodate the deformation of the backfill and subsoil caused by the construction of the backfill, and
 - b) strong enough to be stable against the earth pressure by the backfill weight and compaction forces.
- (3) The use of backfill of high quality; good compaction; and confirmation of high quality of compacted backfill. **Why so important? → the next page!**

Continuous RC slab track 1/2

- Relatively high initial construction cost
- But, a very large reduction of maintenance cost
- Very small allowable total settlement by the compression of the backfill and the subsoil:
 - 30 mm/10 years (for required serviceability)
 - Less than 15 cm (for required restorability after a severe E.Q.)

Requirements for HSR in Japan

By the courtesy of Japan Railway Construction, Transport and Technology Agency and Watanabe, K. (Univ. of Tokyo)



4) Five core construction procedures of RRR GRS structures - 2/2

(4) Before casting-in-place fresh concrete to construct the FHR facing, the end of the settlement by the construction of the backfill to the full wall height should be confirmed by continuously monitoring the settlement of the backfill and subsoil (i.e., **staged-construction**).

(5) The FHR facing should be constructed in such that it is **firmly connected to all the geogrid layers**.

1) Construction of GRS wall w/ the use of FHR facing

2) Deformation of backfill & subsoil

3) Construction of FHR facing

2. Explanation of Key Construction Procedures for RRR GRS structures

2-1. Overview

2-2. Theoretical and practical background for better understanding of the importance of the key construction procedures

2-3. Steps likely to be taken and what RRR-I can do

Appendix: Some details of the key construction procedures

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2-3. Steps likely to be taken and what RRR-I can do (1):

It is anticipated that the following **Steps 1 through 5** are taken. By taking steps with higher numbers shown below, we can better ensure satisfactory performance of the constructed RRR GRS structures.

Step 1) Preparation of a **basic working plan of the preparation and construction procedures (including a time table)** by the contractor based on TS. (RRR-International will review this document on request)

Step 2) Confirmation of the contents of the following documents by the contractor and related parties to prepare a **detailed working plan of the preparation and construction procedures**.

2A) A pair of manuals for the design and construction of RRR GRS structures
 2B) This document and a complementary note of TS (both after necessary revisions) (Partly explained in this WS. RRR-I will further explain these documents on request)

Step 3) Preparation of a **detailed plan of the preparation and construction procedures (including a time table)** by the contractor (RRR-International will review this document on request)

(to be continued)

2-3. Steps likely to be taken and what RRR-I can do (2) (continued):

To establish the **detailed construction procedures** to be applied to the construction of the GRS structures for High Speed Rail in India

Step 4) On site confirmation of **the detailed construction procedures at the site of the construction of GRS structures for High-Speed Rail prior to its start** (RRR-I is prepared to join this project on request).

In place of Step 4, Step 5 may be taken when judged to be necessary:

Step 5) On site confirmation of **the detailed construction procedures** by constructing the whole or part of a **full-scale model of GRS retaining wall and/or GRS bridge abutment** (RRR-I is prepared to join this project on request).

(to be continued)

2-3. Steps likely to be taken and what RRR-I can do (3) (continued):

For Step 4) and/or Step 5), it is necessary to prepare a working plan based on the results of Steps 1), 2) and 3). This working plan should include at least the following items.

- (For step 5) selection of an **appropriate test site** where the subsoil does not include a soft soil layer (or layers) and the compression of the subsoil by the construction of the reinforced backfill to the full wall height will finish within less than around two weeks.
- Confirmation of **the availability of the construction materials** (including geogrid reinforcement and temporary facing unit) that have the properties that satisfy the requirements described in TS.
- Relevant confirmation program for **the items of the step-by-step construction procedure**.
- Relevant **evaluation program** for K_{30} values, the degree of compaction and the water content of compacted backfill as specified in TS and the related manuals.

2. Explanation of Key Construction Procedures for RRR GRS structures

2-1. Overview

2-2. Theoretical and practical background

for better understanding of the importance of the key construction procedures

2-3. Steps likely to be taken and what RRR-I can do

Appendix: Some details of the key construction procedures

Appendix: Some details of the key construction procedures

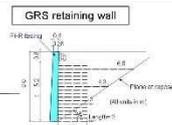
The proper execution of the key construction procedures is a must for the project to be successful.

In this Appendix, their essence is explained together with the background for better understanding of TS. The full details are explained in:

- **Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures,**
RRR Association
- **Manual for the design and construction of RRR GRS Bridge Abutment,**
Railway Technical Research Institute (RTRI) and Japan Railway Construction, Transport and Technology Agency (JRTT), November 2020

Key construction procedures for GRS retaining walls explained in Appendix

- Excavation/Leveling of Ground and Facing Foundation
- Preparation of Geogrid Reinforcement
- Cutting & Installation of Geogrid
- Preparation of Temporary Facing Units of Welded Steel Wire Mesh
- Arrangement of L-shaped Temporary Facing Unit
- Preparation of Backfill Material
- Spreading of Crusher Run and Backfill Material
- Compaction of Crusher Run and Backfill
- Evaluation of the Compacted State and Properties of Compacted Backfill
- Wrapping-Around of Temporary Facing Unit with Geogrid
- Finishing of Backfill Construction
- Observation of Deformation of Backfill and Subsoil
- Construction of Full-Height RC facing



Key construction procedures for GRS retaining walls:

a) Excavation/Leveling of Ground and Facing Foundation (see Fig. 1)

When a GRS RW is constructed on an existing slope of embankment or a natural slope, the slope shall be properly excavated with proper bench-cutting.

[Background]

If the slope is not excavated properly and sufficiently as indicated in the drawing, the geogrid layers at the low levels in the wall may become too short.

If the slope is not properly bench-cut, the stability against a sliding along the interface between the slope and the backfill of GRS retaining wall may become insufficient.

These inadequate procedures result in a decrease in the stability and an increase in the deformation of GRS structures, which could eventually threaten safe operation of High Speed Railway while increasing the maintenance cost.

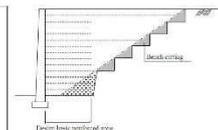


Figure 2.2.4-1 Bench-cutting of existing embankment slope surface

Fig. 1

Page 102, "Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures", RRR Association

b-1) Preparation of Geogrid Reinforcement

A sufficient amount of the geogrid as the reinforcement having the properties specified in TS should be prepared.

[Background]

There are a number of different types of geogrid available in the market. However, for the use of any of them in this project, it is required that the geogrid has been validated to have a sufficient long-term durability against high pH in particular. This validation is a must for the use for the GRS structures in this project, because, unlike other types of GRS structures, because the geogrid makes a direct contact with fresh concrete and is buried inside the cast-in-place RC concrete. Besides, the full-height RC facing staged constructed is one of the essential structural components.

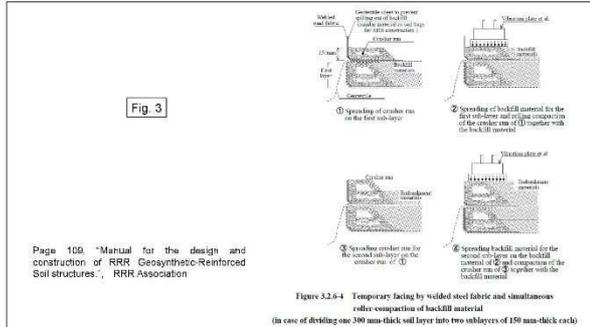
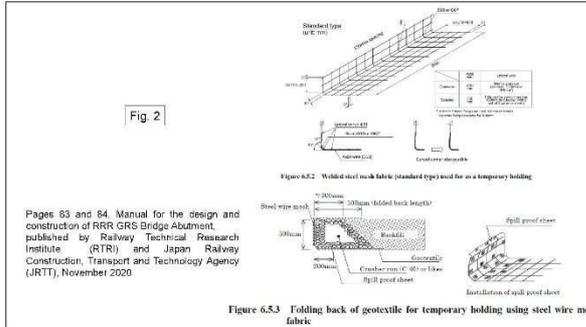
A low durability of geogrid against a high pH results in a gradual loss of its tensile strength and stiffness, which results in a gradual decrease in the stability and a gradual increase in the residual deformation of GRS structures. This may eventually result in an intolerably low level of wall performance threatening safe operation of High Speed Railway while increasing the maintenance cost.

b-2) Cutting & Installation of Geogrid

The geogrid should be cut according to its dimensions described in the design drawing. The length of each geogrid sheet should be longer by at least 80 cm than the length of the main part arranged inside the backfill (see Figs. 2 and 3 on the next two pages). This extra part with a length of at least 80 cm is used to fully wrap around the temporary facing unit and a mass of crusher run placed behind and on the unit.

The geogrid sheets should be installed carefully, especially in the zone where the backfill is to be reinforced with geogrid. Each geogrid layer should be installed after the surface of the immediately underlying soil layer has been levelled. The overlapping along the side edges in the longitudinal direction of the neighboring geogrid sheets should be at least 10 cm.

[Background] An inadequate arrangements of geogrid layers at and around the temporary facing unit results in the loss of the local stability at the connection of geogrid layers to the full-height RC facing, which decreases the global stability of the wall and gradually increases the deformation of GRS structures, eventually threatening safe operation of High Speed Railway while increasing in the maintenance cost.



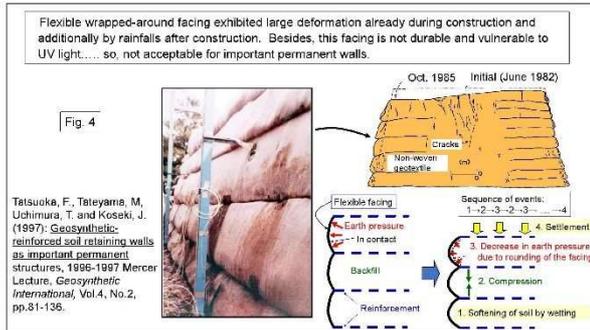
c-1) Preparation of Temporary Facing Units of Welded Steel Wire Mesh (see Figs. 2 & 3 on the immediately preceding pages)

As temporary facing units, a set of steel wire mesh should be arranged at the shoulder of each soil layer of the GRS retaining wall and the GRS bridge abutment before the spreading of crusher run and backfill for the soil layer to be compacted.

[Background]
Without the use of proper temporary facing units,
1) the soil near the wall face is not compacted sufficiently, and
2) the completed full-height RC facing is not firmly connected to the reinforcement layers (i.e., geogrid layers).

These consequences result in a decrease in the stability and an increase in the deformation of GRS structures, eventually to an intolerably low level threatening safe operation of High Speed Railway increasing the maintenance cost.

Fig. 4 (the next page) shows large deformation of a full-scale test GRS retaining wall constructed without using temporary facing units. Even with GRS structures using FER facing, when if improper temporary units that are not stiff enough are used, the wall would deform excessively when subjected to earth pressure and compaction forces during wall construction, as seen in Fig. 4. Large wall deformation may continue after the wall completion due to the continuing deformation of the part immediately back of the full-height RC facing due to large damage by excessive deformation to the temporary facing units.



c-2) Arrangement of L-shaped Temporary Facing Unit (see Fig. 2)

After having installed each geogrid sheet to reinforce the backfill, a L-shape temporary facing unit of welded steel wire mesh is arranged above the geogrid layer at the shoulder of each soil layer. The neighboring units should be arranged not overlapped with each other and not leaving a space in between. The bottom part of each temporary facing unit should be fixed to the underlying backfill using two steel anchor pins to prevent the unit to move during the subsequent backfill construction work.

Then, a piece of geogrid sheet (spill-proof sheet) is fixed to the inside faces of the unit (see Figs. 2 and 3). This geogrid sheet should have an aperture that is small enough to prevent the spilling out of the crusher run particles that is be subsequently placed back and above the unit while large enough to allow the fresh concrete that is later cast-in-place to smoothly penetrate into the crusher run particle zone

[Background]
An inadequate arrangements of temporary facing units holding crusher run decreases its stability, which results in a loss of the stability and an increase in the deformation of GRS structures, eventually to an intolerably low level threatening safe operation of High Speed Railway while increasing the maintenance cost.

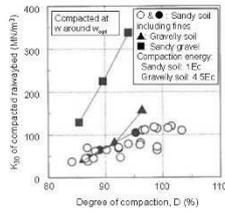
d-1) Preparation of Backfill Material
A sufficient amount of the backfill material of Type A having properties specified in TS should be prepared.

[Background]
According to Table 14 of "4.4.2.3 Criteria for backfill" of TS, it is required that, basically, every value of K_{30} is at least 70 MN/m³ and the average is at least 110 MN/m³. On the other hand, it is indicated in Fig 5 on the next page that the K_{30} values obtained with G class backfill are generally much higher than those with S class backfill when compacted at water content around the respective optimum water content.

In case it is found that it is difficult to obtain the required values of K_{30} specified as above with S class backfill, this problem could be alleviated by using relevant G class backfill. On the other hand, the K_{30} value of S class backfill may increase noticeably by decreasing the water content from the optimum water content. However, if the compaction water content is excessively lower than the optimum water content, the K_{30} value could decrease considerably from a high value by wetting or saturation during a period of service of the railway. This situation should be avoided.

Often a low quality soil (typically having too much fines and/or with a too high, or too low, water content) is available at low cost. The use of a low quality soil that is compacted insufficiently usually results in too low shear strength and too low stiffness of the compacted soil. This results in a decrease in the stability and an increase in the deformation of GRS structures that would continue even after the start of High-Speed Railway, eventually to an intolerably low level threatening safe operation of High Speed Railway while increasing the maintenance cost.

Fig. 5



Appendix Fig.33.17: Relationship between K_{60} and D value for railway bed backfill
 "Railway Technical Research Institute, Japan (2007): Design Standards for Railway Structures and Commentary (soil structures), Railway Technical Research Institute, Appendix 33, pp. 434 (in Japanese)."

d-2) Spreading of Crusher Run and Backfill Material

Crusher run and backfill should be spread firstly on the prepared ground surface then on the underlying backfill layer taking into account the following factors.

- 1) Crusher run should be spread behind and on the temporary facing unit. This crusher run functions as a vertical drain layer immediately back of the full-height rigid facing in the completed wall.
- 2) It should be confirmed that the water content of the backfill material is in a range specified in TS: i.e., between 3% below and 1% above the OMC determined by compaction tests using the compaction energy of Modified Proctor. The backfill material is spread by using a backhoe carefully in such that the underlying geogrid sheet is not distorted and not damaged. A bulldozer should not be used in this work.

For GRS retaining walls, it should be confirmed that the thickness for each soil layer when spread is evenly 35~45 cm so that the compacted thickness becomes evenly 30 cm.

e) Compaction of Crusher Run and Backfill

Each soil layer consisting of the crusher run behind and on the temporary facing unit and the backfill material for the main part of the wall should be compacted together after both have been spread.

The backfill should be properly compacted by using a compaction machine to each specified compacted thickness, equal to 30 cm. Heavy compaction machine shall move in parallel to the wall face. The backfill should not be compacted in the direction perpendicular to the wall face so that the geogrid layer is not waved. Heavy compaction machine should be operated without making a sudden turn and/or a sudden stop during the compaction work so that the compacted soil layer and geogrid layer are not damaged.

In an about 1.0 m-wide zone immediately back of the temporary wall face, compaction shall be done by using a hand-operated compaction machine. The use of a heavy compaction machine in this zone may damage the temporary facing unit and others that are located in this zone. This notion is also to avoid a falling down accident of a heavy compaction machine from the temporary crest of the backfill when not operated carefully enough.

(to be continued)

e) Compaction of Crusher Run and Backfill (continued)

When constructing a GRS retaining wall or a GRS abutment, each temporary facing units should be arranged with a proper setback (typically about 1 - 2 cm) relatively to the unit immediately below so that the alignment of the temporary wall face at the end of the construction to the full wall height is maintained vertical enough.

[Background]

This setback is to ensure the thickness of "the full-height RC facing constructed by casting-in-place the fresh concrete over the temporary facing units" indicated in the drawing. The arrangements of temporary facing units without a proper set back results in an inclination from the vertical of the temporary wall face that becomes larger at higher wall levels. Then, the concrete facing becomes thinner than the one specified in TS with this trend becoming stronger at higher levels of the wall.

To evaluate the amount of proper setback, the following on-site method is known to be effective. During a trial construction of GRS retaining wall (and/or a GRS bridge abutment), the ultimate cumulative lateral external displacement Δ at the front vertical face of a given temporary facing unit that would take place by the construction of the current soil layer and subsequent overlying soil layers is evaluated. To this end, at a couple of temporary facing units, the horizontal movement at the target arranged on the vertical front face of the temporary facing unit is measured before the start of the construction of the current soil layer and also at the end of the construction of each of the subsequent overlying five soil layers.

f) Evaluation of the Compacted State and Properties of Compacted Backfill

The dry density ρ_d , and the water content w , and the K_{60} values of the compacted backfill are measured at relevant locations as specified in TS and it is examined whether these values satisfy the specified requirements. These measurements are repeated as required in the course of backfill construction to the full wall height.

[Background]

It is specified in TS that, basically, the w value of the fill material is not lower by 3% and not higher by 1% than the optimum evaluated by the standard laboratory compaction test using the compaction energy level (CEL) of Modified Proctor (4.5Ec). $[w_{opt}]_{4.5Ec}$, so that the maximum dry density with respect to water content, $[\rho_{max}]_{4.5Ec}$, evaluated by the laboratory compaction test, or a value close to that, is achieved in the field compaction. It should be confirmed that all the measured field values of the degree of compaction, $[D]_{4.5Ec}$, are at least the specified lower bound value (i.e., 95%). $[D]_{4.5Ec}$ is defined as the ratio of the field dry density, ρ_d , to the maximum dry density, $[\rho_{max}]_{4.5Ec}$, times 100%.

Failure to satisfy the required values of $[D]_{4.5Ec}$, w and K_{60} specified in TS may result in an increase in the deformation of the wall that would continue during the operation of High-Speed Railway while increasing the maintenance cost. In particular, a very limited amount of settlement is required for proper performance of RC continuous slab track. Despite the above, it is quite difficult to find this problem even if it is existing when the wall is completed. Even if the problem is found, it is not possible to alleviate this problem by reconstructing partly or fully the structure after the start of High-Speed Railway. Therefore, although it is time-consuming, this confirmation process is indispensable.

g) Wrapping-Around of Temporary Facing Unit with Geogrid

On the levelled surface of each compacted soil layer, geogrid shall be arranged at the location specified in the drawing (see Fig. 3). The geogrid sheet should be longer by at least 80 cm than the length inside the backfill. The extra part of geogrid sheet should be extended towards the outside of the wall before arranging the temporary facing unit. This extra part is then rolled up to wrap-around the temporary facing unit and crusher run together to start the spreading the backfill.

Drain pipes shall be installed at the designated location.

[Background]

Without a proper wrapping-around process, the connection between the full-height RC facing and the reinforcing geogrid layers become unreliable, which could result in a decrease in the stability of the wall and an increase in the deformation of the wall.

Without proper arrangements of drain, the pore water pressure may develop in the wall by heavy rain, which decreases the stability of the wall and increases the deformation of the wall.

h) Finishing of Backfill Construction

At the end of backfill construction to the full wall height, the surface at the crest of backfill should be covered with an about 15 cm-thick layer of compacted crusher run, then covered with a plastic water-proof sheet.

[Background]

Without this protection work, the surface layer of compacted backfill may be damaged by unforeseeable mechanical disturbances and wetting by heavy rain during a subsequent period before the construction of continuous RC slab and others. As the compression of the surface layer of compacted backfill controls most sensitively the settlement of the continuous slab, this finishing work is indispensable for safe operation of high speed trains keeping low the maintenance cost.

i) Observation of Deformation of Backfill and Subsoil

Upon the end of the construction of the backfill to the full wall height, the observation of the settlement at several relevant places at the crest of the completed backfill and on the ground surface immediately in front of the bottom of the temporary wall face is started. The observation is made occasionally to obtain a time history of the settlement by which the end of settlement can be confirmed. The observation is continued until this confirmation is made.

[Background]

Without this observation, it is not possible to ensure that the settlement of the backfill due to its compression and the one of the subsoil caused by the construction of the backfill with a help of temporary facing unit to the full wall height has finished. Possible troubles due to the construction of full-height RC facing before the end of this settlement are described on Page 44.

j) Construction of Full-Height RC facing

After the compression of the backfill and the subsoil taking place by the construction of reinforced backfill to the full wall height is completed, the full-height RC facing is constructed by the following sequences:

- (1) assembling of scaffold;
- (2) assembling of steel reinforcement rebar for the RC facing;
- (3) arrangement of rebar to fix the outside concrete formwork to the temporary facing units;
- (4) arrangement of outside concrete formwork; and
- (5) casting-in-placing of fresh concrete in the space between the outside concrete formwork and the temporary wall face consisting of temporary facing units wrapped-around with geogrid sheets (Fig. 6 on the next page).

As the fresh concrete penetrates into only a thin front zone of the crusher run zone held by each temporary facing unit, the crusher run functions as a vertical drain layer immediately back of the completed full-height RC facing.

(to be continued)

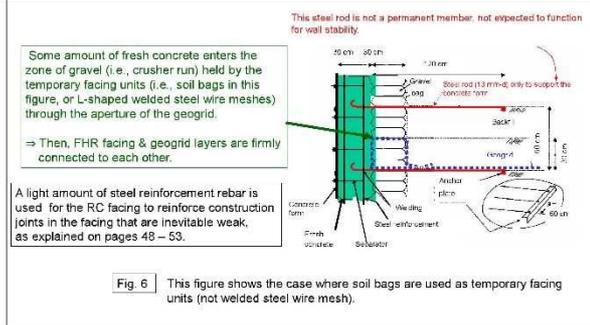


Fig. 6 This figure shows the case where soil bags are used as temporary facing units (not welded steel wire mesh).

j) Construction of Full-Height RC facing (continued)

[Background]

The wall deformation usually starts from the deformation in the zone immediately behind wall face. This process can be effectively restrained by means of a properly constructed full-height RC facing firmly connected to all the reinforcement layers. Fig. 7 shows relatively large deformation of a full-scale test GRS retaining wall constructed using soil bags as temporary facing units but not using such a stiff full-height RC facing as the one to be used for the GRS structures in this project. The wall deformation seen in Fig. 7 is too large to support High-Speed Railway.

The construction of the full-height RC facing after the end of settlement is to avoid:

- (1) the damage to the connection between the RC facing and the geogrid layers caused by post-construction relative settlement between them; and
- (2) uncontrollable post-construction settlement of the facing, which should be avoided particularly for the one supporting a bridge girder with GRS bridge abutment.

This staged construction procedure makes possible the construction of the facing without using a pile foundation for settlement-sensitive GRS structures (particularly, GRS bridge abutments).

As shown on pages 48 - 53, the weak point of the FHR facing is horizontal construction joints at the intermediate heights of the facing. To alleviate this problem, the FHR facing is lightly steel-reinforced.

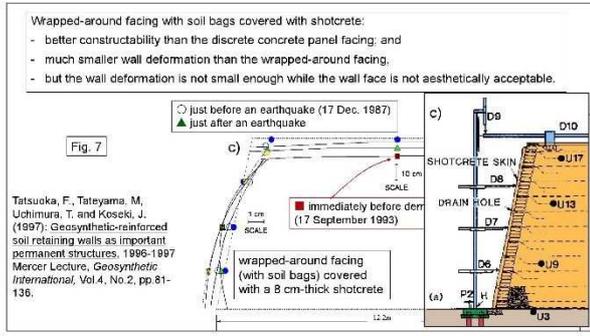


Fig. 7 Tatsuoka, F., Tateyama, M., Uchimura, T. and Kosaki, J. (1997): Geosynthetic-reinforced soil retaining walls as important permanent structures, 1996-1997 Mercer Lecture, *Geosynthetic International*, Vol. 4, No. 2, pp.81-136.

Key Construction Procedures Exclusive for GRS Bridge Abutment:

c/BA) Preparation of Backfill Material

(1) Laboratory compaction tests of backfill material

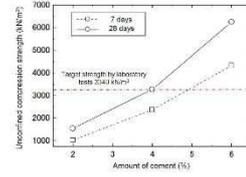
The maximum dry density and the optimum water content of the backfill material should be determined by performing standard laboratory compaction tests using Modified Proctor. It is known that, with cement-mixed soil using such a relatively small amount of cement as used in this project, the compaction characteristics do not change noticeably by cement-mixing.

(2) Laboratory mixing proportion tests for the backfill of the approach block

With the water content equal to the optimum water content determined as above, the amount of cement to be added to the backfill material of G Class soil should be determined in such that the specified target value of laboratory unconfined compression strength at a curing period of 28 days, which is at least 2,000 kN/m² as described in the drawing, is achieved. A typical set of unconfined compression test results when the target strength is 3,340 kN/m² is shown in Fig. 8 on the next page.

To complete the works (1) and (2) together will take about six weeks.

Fig. 8



Appendix Figure 2 Results of laboratory compression tests for the design of mix proportion

Page 100, Manual for the design and construction of RRR GRS Bridge Abutment, published by Railway Technical Research Institute (RTRI) and Japan Railway Construction, Transport and Technology Agency (JRRT), November 2020

d-1/BA) Mixing of Backfill Material with Cement and Water

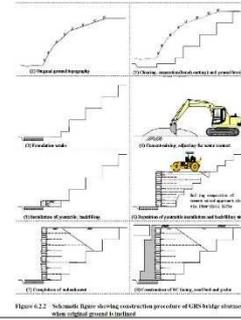
Backfill material of soil Type A should be mixed uniformly firstly with cement powder and then with water following the mixing proportion that has been determined to satisfy the properties specified in TS (i.e., step (4) in Fig. 9 on the next page). The target water content at the time of mixing should be the OMC determined by compaction tests using the compaction energy of Modified Proctor. Fig. 10 typically shows pictures of this mixing work on site.

[Background]

The strength and stiffness of cement-mixed soil is highly sensitive to variations of not only: 1) the amount of cement; 2) curing period; 3) soil type; 4) the compacted dry density; but also 5) the water content at mixing. The strength and stiffness cement-mixed soil usually exhibits a shape peak when mixed at the OMC under otherwise the same conditions.

When the backfill is not uniformly mixed with cement powder and water at the OMC, the strength and stiffness of cement-mixed backfill in the field will exhibit a larger scatter, while large part of core samples retrieved from the field compacted cement-mixed backfill would exhibit strength values that are noticeably lower than the allowable lower bound.

Fig. 9



Page 78, Manual for the design and construction of RRR GRS Bridge Abutment, published by Railway Technical Research Institute (RTRI) and Japan Railway Construction, Transport and Technology Agency (JRRT), November 2020

Figure A-22 Schematic figure showing construction procedure of GRS bridge abutment mix (right panel is omitted)



Fig. 10

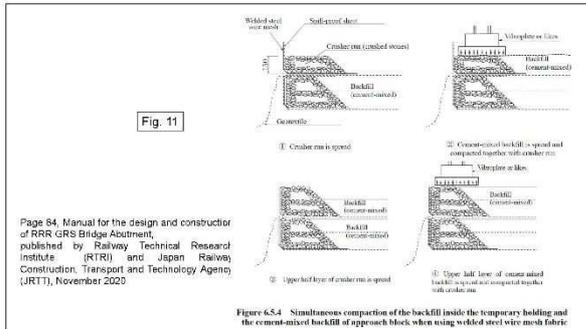
d-2/BA) Spreading of Uncement-mixed Crusher Run and Cement-Mixed Backfill Material

Crusher run (not cement-mixed) should be spread behind and on the temporary facing unit in two lifts for a total compacted thickness of 30 cm (see Fig. 11). The cement-mixed backfill is spread over the geogrid sheet behind the crusher run held by the temporary facing unit by using a backhoe then manually carefully in such that the geogrid sheet is not distorted and not damaged. A bulldozer should not be used in this work. The crusher run (not cement-mixed) and the cement-mixed backfill are spread and compacted in two 15 cm-high lifts to a completed total thickness of 30 cm. It should be confirmed that the thickness for each lift when spread is evenly about 17-22 cm so that the compacted thickness of the lift becomes evenly 15 cm.

[Background]

The compacted thickness of the lift of crusher run and backfill in the approach block of GRS bridge abutment is 15 cm, which is a half of the one for GRS retaining wall (i.e., 30 cm). This is to obtain uniform higher strength of the cement-mixed soil by better compaction. A too large lift is one of the main causes for poor compaction. A high stability with a limited amount of deformation of the approach block is crucial for a high stability and a limited amount of displacement of the facing that is not supported with a pile foundation.

The crusher run held by temporary facing units are not cement-mixed so that it can absorb small relative residual displacements between the facing and the approach block if it takes place.



e/BA) Compaction of Uncement-Mixed Crusher Run and Cement-Mixed Backfill Material

A 30 cm-thick soil layer should be produced by spreading and compacting in total two 15 cm-high lifts.

Each lift consisting of the uncemented crusher run behind and on the temporary facing unit and the cement-mixed backfill material for the approach block should be compacted together after both having been spread (see Fig. 11).

Importantly, the compaction should be made in the same day when the backfill is mixed with cement and water.

Each lift should be compacted properly by using a compaction machine to each specified compacted thickness, equal to 15 cm. Heavy compaction machine shall move in parallel to the wall face. The backfill should not be compacted in the direction perpendicular to the wall face so that the geogrid layer is not waved. Heavy compaction machine should be operated without making a sudden turn and/or a sudden stop during the compaction work so that the compacted soil layer and geogrid layer are not damaged.

[Background]

It is a must to compact the cement-mixed backfill in the same day when mixed with cement and water. This is because the compaction of cement-mixed soil that has somehow solidified due to the hydration of cement by leaving without compaction for a too long period may result in very low strength and stiffness even after a long period of curing after compaction.

For Q & A

Note on Steps Likely to be Taken

Note: Steps 1 – 5 described below are also relevant to all the contractors that will construct RRR GRS structures.

STEP 1:		
Likely actions of contractor(s)	Contributors to be made on request	Based on TS, contractor(s) prepare(s) a basic working plan of preparation and construction procedures to be applied to the construction of RRR GRS structures for India High Speed Railway.
Possible contributions & view of RRR-I	View on further actions to be taken	None
As this RRR GRS structure project is the first one in India, it will be seen that only the basic working plan prepared as above is insufficient, but a detailed working plan prepared based on more detailed information, in addition to TS is required.		
STEP 2:		
Likely actions of L&T and T&AP	Case A Case B (more likely)	Contractor(s) confirm(s) the contents of the two manuals for RRR GRS relating walls and bridge abutments to prepare a detailed working plan. Contractor(s) confirm(s) the contents of the two manuals and other related documents including 'Key construction procedures and Their Execution' and 'Complementary role of TS' to prepare a detailed working plan.
Possible contributions & view of RRR-I	Contributions to be made on request View on further actions to be taken	On appropriate opportunities, RRR-I explains the contents of the two manuals and other related documents to contractor(s) for them to prepare a detailed working plan. A draft of detailed working plan will be prepared based on the two manuals and related documents.
Note: 1) For Step 2, it is necessary to provide the two manuals and related documents to related contractor(s). 2) Appendix 2 of the document, 'Key construction procedures and Their Execution' is a concise summary of the key construction procedures of RRR GRS structures that are described in details in the two manuals.		

STEP 3:		
Likely actions of contractor(s)	Contributors to be made on request	Contractor(s) prepare a draft of detailed working plan.
Possible contributions & view of RRR-I	View on further actions to be taken	RRR-I reviews the draft. On request, RRR-I creates a sample of the detailed working plan. To be confirmed with RRR-I and a smooth execution of the GRS structures for RRR-I, it is necessary to submit the detailed working plan for RRR-I's confirmation.
STEP 4:		
Likely actions of L&T and T&AP	Contributors to be made on request	The detailed working plan of preparation and construction procedures is confirmed internally. RRR-I reviews the working plan for the on-site control on project in advance of the project.
Possible contributions & view of RRR-I	View on further actions to be taken	RRR-I reviews the working plan for the on-site control on project in advance of the project. It would be necessary to confirm all the details of the construction procedures. Immediately after the start of the construction, it is necessary to submit the detailed working plan to RRR-I for its confirmation. It is necessary to submit the details of construction procedures by conducting full-scale test GRS on-site at the beginning of the construction of the GRS structure.
Note: In case Step 4 and/or Step 5 is/are taken, in advance of the on-site construction project, it is necessary to check the availability of the construction materials, the water supply with RRR GRS materials, including water (e.g., 30 days period in Type II) and/or temporary facilities, units of mixed steel mesh as specified in TS. The understand that RRR-I will oversee the process from application to the end of the on-site construction project.		
STEP 5:		
Likely actions of L&T and T&AP	Contributors to be made on request	To be confirmed with the reference of 1), the details of the construction procedures, whole or part of the whole TS (GRS and/or adjacent) construction separately, in advance of the construction of the GRS structure.
Possible contributions & view of RRR-I	View on further actions to be taken	RRR-I reviews the working plan for the on-site control on project in advance of the project. The details of the construction procedures, such as the availability and quantity of construction materials, the water supply, the TS procedures, etc. All related parties should be confirmed with the completion of the detailed working plan that is submitted to the RRR-I.
Note: The construction of the on-site construction project should be confirmed in the construction of the GRS structures for RRR-I.		

I-3-2 Susumu Nakajima (Railway Technical Research Institute)

High Speed Rail in India (Mumbai-Ahmedabad: Section C4)

Explanation of the relative parts of technical issues for successful construction of GRS retaining walls and GRS bridge abutments following TS

Susumu Nakajima (nakajima.susumu@rtri.or.jp)
(Laboratory head of foundation and geotechnical engineering laboratory, RTRI)

Railway Technical Research Institute, Japan (RTRI)
International Association of RRR Construction System (RRR-I)

RRR-Geosynthetic-Reinforced wall and abutment

Reinforced-soil Railroad/Road structures with Rigid facing (RRR method)

- **Composite structure** consisting of the **continuous rigid wall facing**, **sufficiently compacted backfill using regulated material**, and **reinforcement**
- Wall facing is free from the settlement due to embankment construction thanks to the **staged construction**.

Settlement allowed in embankment supporting Slab track

- Only very small settlement is allowed both for backfill and subsoil.
 - For required serviceability, total settlement after placing the slab track should be restricted less than 30 mm for the design life.
 - For required serviceability, only 10 mm of consolidation settlement of the subsoil is allowed in 10 years.
 - For required restorability, only 100 mm of residual settlement is allowed even after a massive earthquake.

Material regulations and compaction control standards, which reflected specifications prepared for MAHSR project, must be correctly understood and operated.

Material regulation

Material regulation for backfill soil
Well graded sand and gravel with less fine content is usable as the backfill material [categorized as A group].

Performance rank	Backfill materials
I (Slab-track.)	[A group]
II (Ballasted track)	[A group] [B group]

Following are unsuitable as backfill materials

1. Bentonite, acid clay, sulphuric clay and other expandable soil or rock.
2. Serpentine, mudstone with a slaking rate of 50% or more, and other rock that has been remarkably weathered by water absorption expansion.
3. Highly organic soil and other highly compressible soil
4. Frozen soil

Material regulation (contd.)

Material regulation
Well graded sand and gravel with less fine content is usable as the backfill material [categorized as A group].

Group code	Soil class code
[A group]	(G) (G-S) (GS)
	(G-F) (G-FS) (GS-F) ¹⁾
	(S) (S-G) (SG) ²⁾
	(S-F) (S-FG) (SG-F) ³⁾
	Crushed hard rock ⁴⁾

¹⁾ Excluding fine fraction that is mainly organic soil
²⁾ Fine fraction, $U_e \geq 10, 1 < U_c < \sqrt{U_e}$
 U_e : Uniformity coefficient, U_c : Coefficient of curvature
³⁾ Excluding fine fraction that is mainly organic soil or volcanic ash soil
⁴⁾ Excluding that with remarkable fissility

Proper material selection is the first step

Material regulation (contd.)

1. Concrete
Concrete material shall conform to Sub-Division 4 in Division 5000 of Building Documents - Part 3, Package No. MAHSR-C-4 Section V13, Employer's Requirements (Technical Specifications)
2. Gravel/Stone/Inert Crushed Stone
The gravel/stone/inert crushed stone shall comply with the distribution curve specified in APPENDIX 1 (1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) (21) (22) (23) (24) (25) (26) (27) (28) (29) (30) (31) (32) (33) (34) (35) (36) (37) (38) (39) (40) (41) (42) (43) (44) (45) (46) (47) (48) (49) (50) (51) (52) (53) (54) (55) (56) (57) (58) (59) (60) (61) (62) (63) (64) (65) (66) (67) (68) (69) (70) (71) (72) (73) (74) (75) (76) (77) (78) (79) (80) (81) (82) (83) (84) (85) (86) (87) (88) (89) (90) (91) (92) (93) (94) (95) (96) (97) (98) (99) (100) (101) (102) (103) (104) (105) (106) (107) (108) (109) (110) (111) (112) (113) (114) (115) (116) (117) (118) (119) (120) (121) (122) (123) (124) (125) (126) (127) (128) (129) (130) (131) (132) (133) (134) (135) (136) (137) (138) (139) (140) (141) (142) (143) (144) (145) (146) (147) (148) (149) (150) (151) (152) (153) (154) (155) (156) (157) (158) (159) (160) (161) (162) (163) (164) (165) (166) (167) 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More strict material regulation for grade stabilized crush stone used for cement approach block. Mix design and field compaction test is also important.

Quality control

Criteria for Upper part of backfill

1) Average value of relative compaction is 95% or more (lower limit value 92%), Average value of K_{30} value: 110MN/m³ or more lower limit value 70MN/m³

The maximum dry density shall be according to "Determination of water content – Dry density relation using heavy compaction (IS: 2720 (Part8)-1983)". The test shall be carried out under compaction in large size mould. In the case of crushed stone, it shall be carried out by drying method, non-repetitive method.

Both criteria shall be simultaneously satisfied.

Quality control(contd.)

1) Average value of relative compaction is 95% or more (lower limit value 92%), Average value of K_{30} value: 110MN/m³ or more lower limit value 70MN/m³

Compaction is done at optimum moisture content.

Legend:
 ○ : SF[Standard compaction]
 ● : SF[Heavy compaction]
 ▲ : GS-F[Heavy compaction]
 ■ : GS-F[GS-F]

Quality control(contd.)

The water contents range of the backfill material (defined water content) shall be set to satisfy Clause 4.4.2.3 of this specification based on Clause 4.4.1.1.

It is important to construct the water content with the optimal water content, and it is necessary to adjust the water content of the material depending on the situation. [From JRS]

Experience shows that most suitable water content falls within a small range of 3% below to 1% above the OMC for most of the soil. [Guideline No.GE:G-1]

Summary

- Composite structure consisting of the **continuous rigid wall facing, sufficiently compacted backfill using regulated material, and reinforcement**
- The backfill material is regulated. Use of **A group soils is mandatory**, among which the use of **gravel soils** tends to make it easier to meet the criteria.
- In case of the upper part of the embankment, The criteria for **relative compaction and K_{30} shall be simultaneously satisfied**.
- As for determination of the maximum dry density, **heavy compaction** should be carried out.
- The **water content management** is also mandatory. For details, you can refer to the JRS or Indian Standard (GE:G-1), Manual for the design and construction of RRR-GRS structures among the references listed as the relevant guidelines in TS.

I-3-3 Takuya Kosaka (International Association of RRR Construction System)

Indian High Speed Railway (Mumbai-Ahmedabad: Section C4)

Proposal of Pilot Construction
of RRR GRS retaining wall and GRS bridge abutment

1

— Contents —

1. General
2. Preparation Work
 - 2-1. Ground conditions at the pilot construction site
 - 2-2. Preparation of construction materials
3. Pilot construction of GRS retaining wall
 - 3-1. Scope of Work
 - 3-2. Sequence of Work
 - 3-3. Description for Sequence of Work
 - 3-4. Time Table
4. Pilot construction of GRS bridge abutment
 - 4-1. Scope of Work
 - 4-2. Sequence of Work
 - 4-3. Description for Sequence of Work
 - 4-4. Time Table
5. Notes complementing the contents of TS
6. Explanation of staged construction

2

1. General (1)

In TS 4.3.2, it is specified that "backfill banking is to be conducted before the actual construction of earth retaining structure".

It is required to confirm the following items that are to be applied to the construction of GRS structures by performing a full-scale test and analysing the results of the test:

- 1) Properties of the construction materials (including the geosynthetic reinforcement and temporary facing unit) that are to satisfy the requirements described in TS.
- 2) Detailed step-by-step construction procedure that follows the descriptions in TS.
- 3) Smooth construction when following the procedures prepared in Step 2) above.
- 4) Ranked performance of constructed structures, including the K_{50} value, the degree of compaction and the water content specified in TS and indicated in the complementary notes.

This proposal was prepared for the contractor to make a construction plan showing in details the schemes of preparation work and execution at the site for the construction of pilot GRS retaining wall and pilot GR bridge abutment.

3

1. General (2)

The structure and construction procedure is different in many aspects between GRS retaining wall and GRS bridge abutment, as shown below. The structure and construction procedure is more sophisticated with GRS bridge abutments.

GRS retaining wall

GRS bridge abutment

It is relevant to construct both of pilot GRS RW and pilot GRS bridge abutment separately from those constructed as part of the railway in advance of the construction of those for the railway.

It is required to construct at least a whole pilot GRS RW and, if feasible, also a pilot GRS bridge abutment. If the whole of pilot GRS bridge abutment is not constructed, it is required to perform a trial work of 1) the mixing design and execution of the mixing of backfill with cement and water; 2) spreading and compaction of several soil layers; followed by 3) the evaluation of the properties (dry density, water content, K_{50} values) of compacted cement-mixed soil layers.

2. Preparation Work

2-1 Ground conditions at the pilot construction site

Before the pilot construction of GRS retaining wall, it is necessary to confirm that the subsoil at the pilot construction site is stiff enough, not including a soft soil layer (or layers), in such that it can be expected that the compression of the subsoil caused by the construction of geogrid-reinforced backfill to the full wall height is relatively small and will take place fast, preferably within about a week after the end of backfill construction to the full wall height.

The construction of full-height RC facing should be started after the deformation of the backfill and subsoil has taken place sufficiently.

5

2-2 Construction materials (1)

a) Geogrid
A sufficient amount of the geogrid having the properties specified in TS should be prepared before the start of the pilot construction. Geogrid used as a spill-proof sheet should also be prepared. The period necessary for the above should be confirmed well in advance.

b) Temporary facing units of welded steel wire mesh and steel rebars

- 1) A set of steel wire mesh, as shown in the figures below, which is arranged at the shoulder of each soil layer of the GRS retaining wall and the GRS bridge abutment, and
- 2) a set of steel reinforcement rebars and others used to construct of full-height RC facing should be prepared before the start of the pilot construction. The period necessary for the above should be confirmed well in advance.

Steel wire mesh

Installation of spill-proof sheet

6

2-2 Construction materials (2)

c) Backfill Materials

A sufficient amount of the crusher run and the backfill material having properties specified in TS should be prepared before the start of the laboratory tests described below. The period necessary to obtain these materials should be confirmed well in advance.

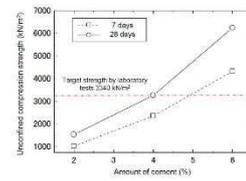
① Laboratory compaction tests of backfill material for both pilot GRS retaining wall and pilot GRS bridge abutment

The maximum dry density and the optimum water content of the backfill material should be determined by performing laboratory compaction tests using Modified Proctor. It will take about three days.

② Laboratory mixing proportion tests for the backfill of the approach block of pilot GRS bridge abutment

With the water content equal to the optimum water content determined as above, the amount of cement to be added to the backfill material of B Class soil should be determined so that the specified target value of laboratory unconfined compression strength at a curing period of 28 days, which is at least 2,000 kN/m² as described in the drawing, is achieved. A typical set of unconfined compression test results when the target strength is 3,340 kN/m² is shown in the figure on the next page.

To complete the work ① and ② together will take about six weeks.



Appendix Figure 2 Results of laboratory compression tests for the design of mix proportion

Page 100, Manual for the design and construction of RRR GRS Bridge Abutment, published by Railway Technical Research Institute (RTRI), Japan Railway Construction, Transport and Technology Agency (JRTT), November 2020

3. Pilot construction of GRS retaining wall

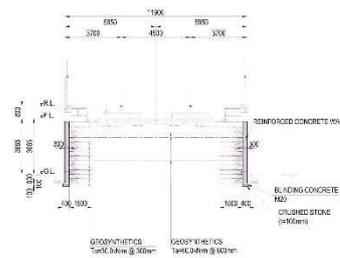
3-1. Scope of Work

3-2. Sequence of Work

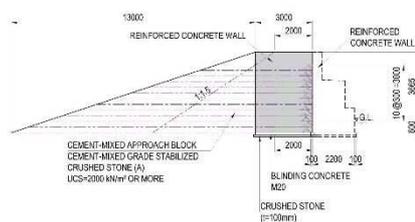
3-3. Description for Sequence of Work

3-4. Time Table

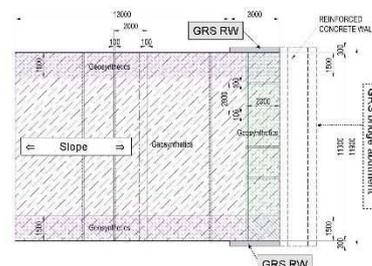
A conceptual diagram of the pilot test embankment is shown on the page 10~12.



Cross-section of typical pilot GRS RWs (although two GRS RWs are shown in this figure, one GRS RW becomes a slope that is extending outside the wall face when only one GRS RW is constructed).



Cross-section of a typical pilot GRS bridge abutment



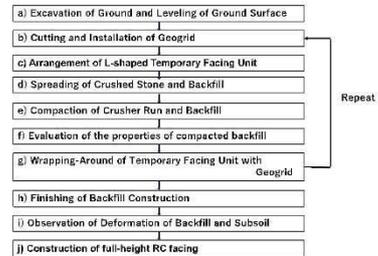
Plan of a typical test embankment consisting of pilot GRS RWs and a pilot GRS bridge abutment

3-1. Scope of Work

The scope of work for construction of GRS retaining wall includes the following:

	Work
a)	Excavation and Leveling of Ground Surface
b)	Cutting and Installation of Geogrid
c)	Arrangement of L-shaped Temporary Facing Unit
d)	Spreading of Crusher Run and the Backfill
e)	Compaction of Crusher Run and Backfill
f)	Evaluation of the Compacted State and Properties of Compacted Backfill
g)	Wrapping-Around of Temporary Facing Unit with Geogrid
h)	Finishing of Backfill Construction
i)	Observation of Deformation of Backfill and Subsoil
j)	Construction of Full-Height RC facing

3-2. Sequence of Work



3-3. Description for Sequence of Work (1)

The followings describe the details of each step of field work for the pilot construction of RRR GRS retaining wall that is indicated in the flow chart shown in the immediately preceding page.

a) Excavating and Leveling of Ground Surface

The construction of GRS RW starts with ground excavation as necessary followed by preparation of levelled ground surface. In order to install geogrid ($T_a=30kN/m$ and $T_b=60kN/m$) and to arrange a drain at the bottom soil layer, the ground surface shall be made level. If bedrock is exposed at the excavated ground surface and/or if the surface layer of excavated ground includes large diameter stone particles, the ground surface shall be made level by spreading good quality soil on the ground surface so that the installed geogrid will not be twisted and damaged.

When a GRS RW is constructed on an existing slope of embankment or a natural slope, the slope shall be bench-cut to prevent a sliding along the interface between the slope and the backfill of GRS RW.

As shown in the construction drawing, a small foundation for the full-height RC facing then the underground part of the facing shall be constructed in advance of the construction of embankment.

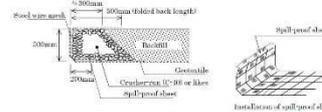
3-3. Description for Sequence of Work (2)

b) Cutting & Installation of Geogrid

The geogrid will be cut according to its dimensions described in the design drawing. The geogrid sheets should be installed carefully, especially in the zone where the backfill is to be reinforced with geogrid.

The length of each geogrid sheet should be longer by 80 cm than the length arranged inside the backfill. This extra part with a length of 80 cm is used to fully wrap around the temporary facing unit and a mass of crusher run placed behind and on the unit (see the figures below).

Each geogrid layer should be installed after the surface of the immediately underlying soil layer has been levelled. The overlapping along the edges in the longitudinal direction of the neighboring geogrid sheets should be at least 10 cm.



3-3. Description for Sequence of Work (3)

c) Arrangement of L-shaped Temporary Facing Unit

(see the figures on the immediately preceding page)

After having installed each geogrid sheet to reinforce the backfill, a L-shape temporary facing unit of welded steel wire mesh is arranged above the geogrid layer at the shoulder of each soil layer. The neighboring units should be arranged not overlapping with each other and not leaving a space in between. The bottom part of each temporary facing unit should be fixed to the underlying backfill using two steel anchor pins to prevent the unit to move during the subsequent backfill construction work.

After each temporary facing unit is fixed, a piece of geogrid sheet (spill-proof sheet) with an aperture that is small enough to prevent the spilling out the crusher run particles that is to be subsequently placed back and above the unit while large enough to allow the fresh concrete that is to be later cast-in-place to penetrate into the crusher run particle zone is fixed to the inside faces of the unit.

3-3. Description for Sequence of Work (4)

d) Spreading of Crusher Run and Backfill Material

① Spreading of crusher run on the temporary facing unit

Crusher run should be spread behind and on the temporary facing unit. This crusher run functions as a vertical drain layer immediately back of the full-height rigid facing in the completed wall.

② Spreading of the backfill material for the main part of the wall

Backfill material of soil Type A should be prepared and it should be confirmed that the water content is in a range specified in the TS. The backfill material is spread over the geogrid sheet by using a backhoe carefully in such that the geogrid sheet is not distorted and not damaged. A bulldozer should not be used in this work.

It should be confirmed that the thickness for each soil layer when spread is evenly 35~45 cm so that the compacted thickness becomes 30 cm.

5. Notes complementing the contents of TS (1-3-1)

1-4) With respect to the appropriate range of water content in soil compaction, according to Clause 4.3.3. 6, the water content range of backfill material shall be set to satisfy Clause 4.4.2.3 of this specification based on Clause 4.4.1.1. Moreover, according to Clause 4.3.2 on Backfill Banking Test, the contractor shall submit the 'Banking Rule and Basis' in order to get desired degree of compaction specified in the Drawings which includes permitted range of appropriate water content.

[Complementary note] Although a specific permitted range of appropriate water content is not indicated in TS and the drawings, in ANNEXURE IV 3.0 of Guideline No. GE: G-1, it is noted that "experience shows that most suitable water content falls within a small range of 3% below to 1% above the OMC for most of the soil".

***GUIDELINES FOR EARTHWORK IN RAILWAY PROJECTS, Guideline No. GE: G-1 (including correction slip no. 1), July, 2003, Geo-technical Engineering Directorate, Research Designs and Standards Organisation Manak Nagar, Lucknow – 11, Ministry of Railway, Government of India**

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5. Notes complementing the contents of TS (1-3-2)

For reference, the following is the related description about the appropriate water content range in soil compaction on page 133 of "Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures".

Before spreading fill material at the compaction place, it should be confirmed that the water content (w) of the fill material is not lower by 3 % and not higher by 1 % than the optimum water content evaluated by the standard laboratory compaction test using the compaction energy level (CEL) equal to Modified Proctor (4.5Ec). [wpd]4.5Ec, so that the maximum dry density with respect to water content, or a value close to that, is achieved in the field compaction controlled to be performed at a CEL of the order of 4.5Ec. To ensure that the compacted state is satisfactory, it should be confirmed that all the measured values of the degree of compaction, D_c , are at least the specified lower bound value (typically 95 %). D_c is defined as the ratio of the field dry density, ρ_d to the maximum dry density, $[\rho_{dmax}]4.5Ec$, times 100 %.

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5. Notes complementing the contents of TS (2-1)

2. Reconfirmation of the compaction control of backfill for the approach block of GRS bridge abutments (Notes complementing the contents of TS 4.4.2.3 Table-15)

The following four criteria should be satisfied as one body:

2-1) The performance rank I is required for the upper backfill supporting RC slab tracks. So, according to Table 15 of "4.4.2.3 Criteria for backfill" of TS, it is required that each value of the degree of compaction is at least 95%.

According to IS 2720 (Part 8), the maximum dry density to calculate the degree of compaction is obtained by laboratory compaction tests using the compaction energy of Modified Proctor.

2-2) According to Table 15 of "4.4.2.3 Criteria for backfill" of TS, it is required that, basically, each value of K_{vc} is at least 150 MN/m³.

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5. Notes complementing the contents of TS (2-2)

2-3) According to Clause 4.2.1, the requirement for backfill material is Group A.

[Complementary note] (the same as the one for item 1-3) However, since it is mixed with cement, S class backfill of A group may also be used.

2-4) About the appropriate range of water content in soil compaction

[Complementary note] (the same as the one for item 1-4) In short, the appropriate range of water content is between 3 % below and 1 % above the OMC determined by compaction tests using the compaction energy of Modified Proctor.



Cement-mixing of backfill



Cement-mixing of backfill



Adjustment of moisture content of backfill

34

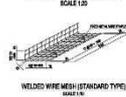
5. Notes complementing the contents of TS (3-1)

3. Construction details of GRS retaining walls and GRS bridge abutments (Notes complementing the contents of TS 4.3.3, 4.3.4)

The followings are the complementary notes prepared to ensure successful construction of geosynthetic-reinforced backfill and full-height rigid RC facing for GRS retaining walls and GRS bridge abutments.

[Complementary notes]

3-1) The temporary facing unit of welded steel wire mesh described in the figure below should be placed on the shoulder of each soil layer when constructing geosynthetic-reinforced backfill. The details of this temporary facing unit are described in Section 3.2.6 Temporary holding at the wall face (pages 105 - 111 in "Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures").



Welded steel wire mesh for temporary holding of the backfill ("Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures").

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5. Notes complementing the contents of TS (3-2)

3-2) The cement-mixed backfill for the approach block of GRS bridge abutment should be compacted in the same day when the backfill is mixed with cement and water.

3-3) The full-height RC facing for GRS retaining walls and GRS bridge abutments should be constructed after having confirmed that most of the deformation and settlement of the backfill and the supporting ground caused by the construction of the geosynthetic-reinforced backfill has taken place.

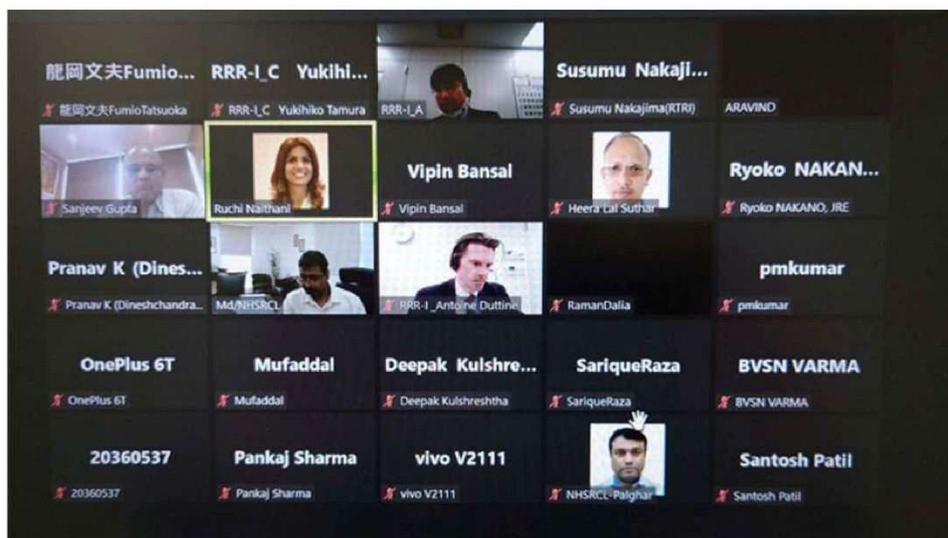
The RC facing is constructed by casting-in-place fresh concrete into a narrow vertical space between the outside concrete formwork anchored in the body of geosynthetic-reinforced backfill and the temporary vertical wall face covered with geosynthetic-reinforcement layers wrapping-around the temporary facing units. An inside concrete formwork covering the temporary vertical wall face should not be used so that the completed RC facing is firmly connected to both of: a) all the geosynthetic reinforcement layers; and b) the temporary facing units of welded steel wire mesh that are wrapped around with geosynthetic reinforcement layers, which becomes an important structural component of the completed GRS structure. (Reference: [3.2.8 RC Facing Work] of "Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures".)

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I-4 Discussions with inquiries and responses

I-4-1 Response to inquiry1 (Minutes of webinar)

Summary of Q&A at the Zoom Work Shop, March 27, 2024



Note: In some of the answers shown below, some supplementary comments are added without changing the contents of the answer orally made during the workshop.

[1]

Q1 : NHSRCL

- Any restriction to the height and length of RRR GRS structures?
- How long is the waiting duration after the construction of full-height geogrid-reinforced backfill (w/o FHR facing) until the start of the casting-in-place fresh concrete to construct the FHR RC facing?

A1 : Tatsuoka, F.

- The largest height so far is about 15 m for RRR GRS retaining walls (RWs) and RRR GRS bridge abutments (BAs). However, this is not the feasible maximum wall height. Taller ones could be constructed: i.e., it is considered at this moment that it is quite feasible to construct 20 m-high RRR GRS structures.

With RRR GRS RWs, there is no limitation to the wall length. The longest continuously constructed GRS RW is about 1 km-long. For a very long RRR GRS RW, to shorten the total construction period, the construction of FHR facing could be started before the construction of geogrid-reinforced backfill (w/o FHR facing) for the whole wall length is

completed. In that case, it is important to confirm in advance that each place where the FHR facing is to be constructed is sufficiently remote from the construction site of geogrid-reinforced backfill in such that, at the site where FHR facing is to be constructed, the settlement of the subsoil does not take place by the construction of geogrid-reinforced backfill.

- b) The waiting duration depends on the compressibility of the subsoil layers. A 90 % of the ultimate settlement of subsoil could be estimated based on the time history of settlement at the site (for example, by the \sqrt{t} method). In case the subsoil does not include compressive soil layer(s), the waiting duration for a 5 m-high GRS structures is typically about two weeks or less. In case the subsoil includes a relatively compressive soil layer(s) in some thickness, the waiting duration will become longer. If the waiting duration should be short enough for some construction restraints, it could be made shorter by the preloading procedure placing a preload fill on the crest of the geogrid-reinforced backfill (w/o FHR facing). This method is also effective to minimize the residual settlement of FHR facing after opening to service of RRR GRS BA. Ground improvement, such as in-place cement-mixing of shallow soil layer(s), could be effective to reduce the settlement of subsoil thereby shortening the waiting duration. The decision in this respect will be made based on the cost-effectiveness of each possible measures.

[2]

Q2 : Not identified

Whether precast concrete panels can be used to construct the FHR facing ?

A2 Tatsuoka, F.

In some previous projects of RRR GRS structures, PC panels were used as the external concrete forms and also as a wall face structural component of the completed FHR facing. In these cases, the use of PC panels was more cost-effective than the setting up of ordinary external concrete forms, which is a temporary structure.

Even when using PC panels, it is the must that the PC panels are eventually firmly connected to the main body of the geogrid-reinforced backfill by casting-in-place fresh concrete in the space between the PC panels and the wall face of the geogrid-reinforced backfill. Besides, the cast concrete layer should be lightly steel-reinforced to ensure a sufficient integrity of the completed FHR facing. The 30 cm-height vertical external face of each temporary facing unit of welded steel wire mesh placed at the shoulder of each soil layer is wrapped-around with the front part of each geogrid layer. The fresh concrete enters the narrow backside space of the wrapping-around geogrid through its aperture then enters the crusher run contained in

the temporary facing unit of welded steel wire mesh through its aperture. There is no case where only PC panels are used to construct the FHR facing without casting-in-place of fresh concrete.

[3]

Q3 : TCAP

- 1) It seems that the compaction control of cohesive soil is made based on the degree of compaction (defined as the ratio of the field dry density to the maximum dry density obtained by laboratory compaction tests), while the compaction control of cohesionless soils (including sandy soils) is made based on the relative density. Why the compaction control of backfill based on the degree of compaction is specified in TS for India High Speed Rail?

A3 : Tatsuoka, F.

It is the ordinary practice in many countries that the compaction control of usual backfill soil to construct soil structures (including sandy soils containing a relatively large amount of fines) is made based on the degree of compaction, not based on the relative density. It will be also the case in this high-speed rail project. The reasons are as follows:

- 1) The compaction procedure of the standard laboratory compaction test to obtain the maximum dry density is somehow representative of field compaction process. On the other hand, various methods are specified to obtain the minimum void ratio (i.e., the maximum dry density) in different countries, while many of them are not representative of field compaction process.
- 2) To obtain the relative density, the maximum void ratio should also be obtained, in addition to the minimum void ratio, which makes the compaction control based on the relative density very time-consuming, so impractical in usual cases.

[4]

Q4 : TCAP

Cracking may take place in the completed FHR RC facing due to its residual settlement caused by the compression of subsoil. What is the measures to avoid this problem?

A4 : Tatsuoka, F.

With RRR GRS structures, FHR facing is constructed by casting-in-place fresh concrete after the settlement due to the compression of the subsoil associated with the construction of geogrid-reinforced backfill (w/o FHR facing) has completed. So, any noticeable settlement of the FHR facing does not take place after its construction, because the total weight of FHR

facing is much smaller than the one of the geogrid-reinforced backfill. Besides, the displacement and deformation of the FHR facing by the weight of the girder and the train load, which are also much smaller than the weight of the backfill, is very small. So, the problem of cracks in the completed FHR facing pointed out in the question does not take place (actually, no such a problem case as above in all the projects).

[5]

Q5 : Suthar (NHSRCL)

① Questions related to PPT 35P:

- a) What supports the external concrete form?
- b) When and how the steel rod (depicted in red colour in the figure shown below) is arranged?
- c) When the steel reinforcement of the facing is arranged? What supports the facing steel reinforcement during the construction of geogrid-reinforced backfill?

A5 : Tatsuoka, F.

There are two types of temporary facing units,

- type I) using soil bags (Fig. A shown below); and
- type II) using welded steel wire mesh fabrics (Fig. B shown below).

Type I was firstly developed. Recently, type II is used more often due to a better cost-effectiveness, which is different in different projects under different construction conditions.

With the two types, the method to support the external concrete form and the steel reinforcement for the facing is different.

Method I): Soil bags are used as the temporary facing units. The external concrete form and the steel reinforcement for the FHR facing are supported by the steel rod (extruded from the geogrid-reinforced backfill, depicted in red colour in Fig. A below) that is anchored in the geogrid-reinforced backfill. These questions a), b) and c) are for this case and they are herein answered.

- a) The external concrete forms are supported by separators that are welded to horizontal L-shaped steel members that are welded to vertical L-shaped members that are welded to the head of the steel rod (extruded from the geogrid-reinforced backfill, depicted in red colour in Fig. A) that is anchored in the geogrid-reinforced backfill. The horizontal and vertical L-shaped steel members are not depicted in Fig. A, but they are depicted in Fig. B.
- b) Each unit of several steel rods is arranged horizontal on the surface of the immediately underlying compacted soil layer. In so doing, the small flange for anchorage at the back end of the unit is inserted into a shallow groove dug in the

underlying soil layer. This arrangement should be done in such that the upper side of the steel rod unit is kept flat and horizontal so that the next geogrid layer that will be arranged on the unit is not damaged when compacting the soil layer that will be placed on the geogrid layer. At the same time, the bottom side of the unit should fit the surface of the immediately underlying soil layer not creating a gap in between so that any weak part is made inside the geogrid-reinforced backfill. After this arrangement of steel rod units, the next geogrid layer is arranged on them. Then, the next soil layer is spread on the geogrid layer.

- c) The lower part of the steel reinforcement for the facing (shown in Fig. A, but not shown in Fig. B) is arranged with the bottom end embedded in the embedded part of the FHR facing before the start of the construction of geogrid-reinforced backfill. The whole of the facing steel reinforcement is arranged welded to the vertical L-shaped steel members. After that, the external concrete forms are arranged supported by separators that are supported by the vertical L-shaped steel members that are fixed to the head of the steel rods.

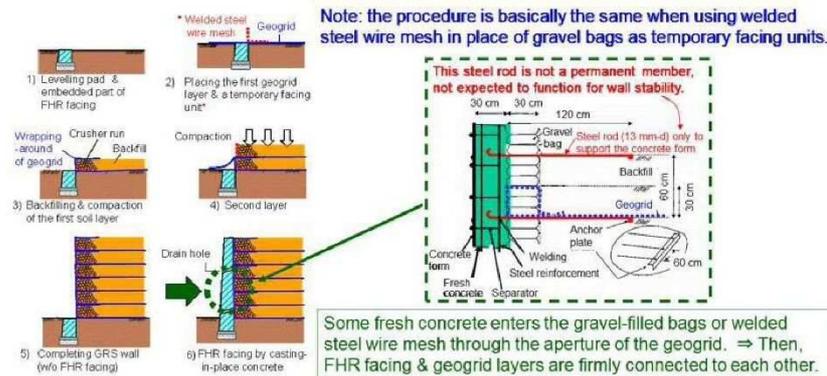


Fig. A) (Vertical and horizontal L-shaped steel members are not shown in this figure).

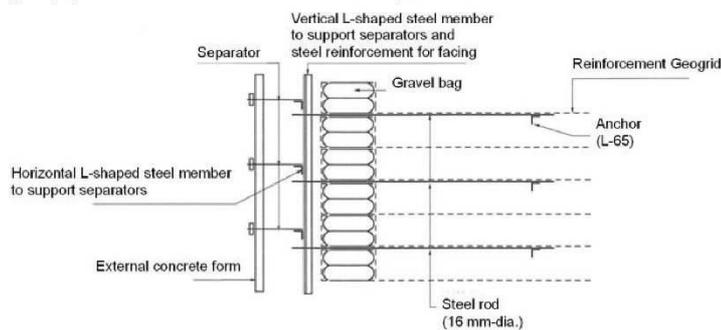


Fig. B) (Steel reinforcement for the facing is not shown in this figure)

Method II): Welded steel wire mesh fabrics are used as the temporary facing units. The external concrete form and the steel reinforcement for the facing are welded to vertical L-shaped steel members that are supported by short hooked steel rods (D10) anchored to the temporary facing unit of welded steel mesh fabrics, as shown in the bottom two figures of Figs. C and D. Separators together with external concrete forms are fixed to these vertical L-shape steel members. The steel reinforcement for the facing (not shown in Fig. C, but shown in Fig. D) is also fixed to these vertical L-shaped steel members.

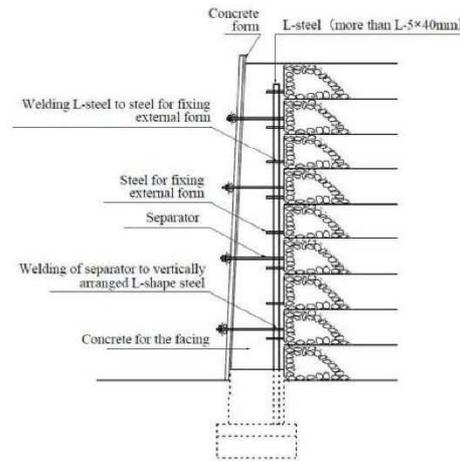


Figure 3.2.8-5 Example of the method to fix concrete form for the facing construction using welded steel fabric

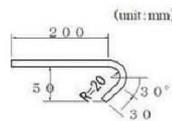


Figure 3.2.8-6 Shape of steel for fixing external form in case of using welded steel fabric

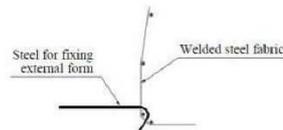


Figure 3.2.8-7 Example of the method to arrange steel for fixing external form to welded steel fabric

Fig. C) (Steel reinforcement for the facing is not shown in this figure)



Fig. D) (After the arrangement of the steel reinforcement for the facing, before the setting up of external concrete form)

[6]

Q6 : SariqueRaza (TCAP)

How to measure the settlement of the geogrid-reinforced backfill constructed to the full wall height? At what locations? How long ? The measurements should continue after the completion of the GRS structure?

A6 : Tatsuoka, F.

The settlement of the geogrid-reinforced backfill (w/o FHR facing) is measured:

- a) at the center of the topmost temporary facing unit, starting immediately after the completion of the geogrid-reinforced backfill (w/o FHR facing); and
- b) at the top of the embedded part of the FHR facing, starting preferably before the start of the construction of geogrid-reinforced backfill, or soon after the start of the construction of geogrid-reinforced backfill.

The measurements are made usually by the ordinary level measurement, but it could be by another more advanced method. It is not required to continue the measurements after the construction of the FHR facing. However, the post-construction measurements will be useful to confirm that the residual settlement of FHR facing is kept very small.

[7]

Q7 : L&T

What a device is used to connect the RC facing to the main body of geogrid-reinforced backfill ?

A7 : Tatsuoka, F.

For RRR GRS structures, a special device, such as metal connector, is not used to connect the FHR facing to the main body of geogrid-reinforced backfill. This connection is made by embedding the following a) and b) in the cast-in-place fresh concrete:

- a) the vertical portion of the geogrid layer that is wrapping-around temporary facing unit;
and
- b) the front vertical portion of the temporary facing unit of soil bag or welded steel mesh fabrics together with contained crusher run.

This connection is achieved by allowing the cast-in-place fresh concrete to enter the narrow backside space of the wrapping-around geogrid through the aperture of the geogrid, then enter the crusher run contained in the temporary facing unit (soil bags or welded steel wire mesh fabrics). It has been confirmed that, when properly constructed, the connection strength achieved in this way is large enough.

[8]

Q8 : L&T

At a site (or sites) of RRR GRS BA to be constructed in front of a tunnel entrance, it seems that it is difficult to smoothly perform “benching cutting as indicated in the drawing” in a stiff natural ground.

A8 : Tatsuoka, F.

The dimensions of bench cutting indicated in the drawing of standard RRR GRS BA was determined by stability analysis in such that the reinforcement geogrid layers that are necessary to ensure the required stability of the GRS BA can be arranged. So, if the dimensions of bench cutting are changed in such that the lengths of some geogrid layers at lower levels in the wall become shorter than those indicated in the drawing, the GRS BA could be endangered due to a decrease in its stability.

If it is planned to change the dimensions of bench cutting for some reasons and if, as a result, the lengths of some geogrid layers at low levels of the wall become shorter, the stability analysis should be performed to ensure that the GRS BA can be stable as required with modified arrangements of reinforcing geogrid layers. Generally, when the geogrid layers at low levels are made shorter, to maintain the same stability of GRS BA, it becomes necessary to increase the width at higher levels of the approach block (consisting of geogrid-reinforced lightly cement-mixed high-quality backfill). This redesign of the structure requires a new stability analysis.

In this respect, it is possible to reduce the amount of bench cutting in the stiff ground without

decreasing the stability of GRS BA by relocating the FHR facing forwards in the direction of the railway axis by a couple of meters. In that case, it becomes necessary to re-design both of the GRS BA and the viaduct to which the GRS BA is connected (i.e., re-determination of the locations and dimensions of these structures while confirming their stabilities).

[9]

Q9 : Vipin (NHSRCL)

What is the tolerance of the wall face inclination?

A9 : Tatsuoka, F.

First of all, with other types of mechanical stabilized earth retaining walls (MSE RWs) for which the facing is constructed before the start of, or simultaneously with, the construction of reinforced backfill, the final alignment of the facing of the completed wall is disturbed by the deformation of the backfill that takes place in an uncontrollable way during its construction. That is, due to noticeable wall deformation during construction, the wall face may exhibit noticeable settlement, globally and/or locally, and noticeable lateral external displacement. For this reason, with these types of MSE RWs, it is often specified in such that the maximum allowable lateral displacement at the top of the facing is 3% of the wall height or 30 cm at the end of wall construction.

With RRR GRS structures, on the other hand, excessive inclination of the vertical face of the constructed FHR facing is not a practical serious issue. This is because, after its construction, noticeable deformation and displacement of the FHR RC facing due to the deformation of the backfill and subsoil associated with the construction of geogrid-reinforced backfill does not take place. The alignment of the wall face of the completed FHR facing can be ensured by its proper construction. With the RRR GRS structures, it is more important and essential to ensure that the thickness of constructed FHR facing satisfies the specified value throughout the wall height. A tolerance of the wall thickness is ± 20 mm is often specified following the ordinary specification for conventional cantilever RC retaining walls. To this end, it is important that the completed temporal wall face before the construction of the FHR facing is vertical enough. A method to achieve this requirement is described in "e) Compaction of Crusher Run and Backfill (continued)" of Appendix of the document explained in this workshop: "Key Construction Procedures and Their Proper Execution".

Q10. Suthar (NHSRCL)

a) What is the situation about the construction of conventional cantilever RWs and RRR GRS

RWs in Japan?

- b) It seems that RRR GRS structures exhibit better performance and are more cost-effective than the conventional cantilever RWs. We have a couple of problems with the conventional type RWs. It seems that this type of RRR GRS structure could be used not only for High Speed Rails in India but also for conventional railways in India.
- c) It is understood that the proper design and proper construction is essential for successful constructions of RRR GRS structures. What companies or organizations we can consult on the design and construction of RRR GRS structures when it becomes necessary?

A10:

- a) For newly constructed RWs for railways in Japan, nearly 100 % is RRR GRS RWs with a very limited number of conventional cantilever RWs.
- b) RRR GRS RWs and BAs were not developed exclusively for High Speed Railways, but they were developed to be used also for conventional railways, roads and others. In actuality, many were adopted in these other fields.
- c) The following three items are essential for successful constructions of RRR GRS structures: 1) the use of proper geogrid reinforcement following the RRR material manual; 2) the proper design following the RRR design manual; and 3) the proper construction following the RRR construction manual. Please make a contact with Mr. Kosaka, T. (the representative of RRR International). As engineers and researchers specialized in RRR GRS structures, he and his colleagues of RRR-International and Railway Technical Research Institute, Japan (including members working for consulting companies specialized in RRR GRS structure) are prepared to work for the design and construction of RRR GRS structures in India.

I-4-2 Response to inquiry2

Summary of Q&A at the RRR for India conventional train lines meeting Zoom meeting, April 17, 2024

Note: In some of the answers shown below, some supplementary comments are added without changing the contents of the answers orally made during the meeting.

【1】 Mr. Suthar (NHSRCL)

Q: How and by whom this design project could be carried out?

Tatsuoka & Best Geo : Best Geotechnics Pvt. Ltd is ready to act as a main contractor for this project, since it is a member of the International Association of RRR construction system, and since it is based in Mumbai, India and has already experience in projects conducted in the Indian state where this project will take place. IGI (Integrated Geotechnology Institute Ltd.), which is a private consulting firm based in Tokyo, can act as a sub-contractor to this project and conduct the detailed design in Japan. IGI hosts the offices of the International and Domestic Association of RRR construction system, and has been a supporting actor in the development of the RRR technology to the Railway Technical Research Institute RTRI Japan and the University of Tokyo. It is responsible for 60 to 70% of all the RRR structures designs performed in Japan since this technology was introduced. IGI also performed the standard design for Indian high speed rail.

<http://bestgeotech.com>

<https://www.igi.co.jp>

Tatsuoka: It should be noted that RRR GRS RWs and BAs were not developed exclusively for High Speed Railways, but they were developed to be used also for conventional railways, roads and others. The required performance, e.g., settlement requirements are naturally stricter for high speed rails and slab tracks but the design methodology is strictly the same. So design for this particular project can be smoothly done just as it was for the India high speed rail, as well as the detailed design if relevant design and subsoil conditions are given.

【2】 Mr. Suthar (NHSRCL)

Q: Does IGI have any international experience in conducting projects overseas?

Tatsuoka: IGI acts usually as a sub contractor to an international consulting company, e.g. JICA or East Japan Railway Consultants to perform the detailed RRR design and provide

support for construction management in collaboration with the International Association of RRR construction system. This is such a case for the India high speed rail.

【3】 Not identified

Q: Is there any experience in Japan working with 25T axle loads?

Tatsuoka: There have been cases where RRR structures have been constructed for very heavy locomotive axle loads or such in Japan. Heavy axle loads remain relatively minor loads compared with all the design loads considered, seismic loads or girder loads for bridge abutments being by far the most critical. So there is no particular issue encountered in the stability and deformation of the main body of GRS structures design for 25T or more axle loads. On the other hand, the design of slab structures and related railway bed soil layers should take into account this increase in the train load.

【4】 Not identified

Q: Does a higher train running speed have an influence on the RRR design methodology?

Nakajima: In Japan initial running speed for high speed train line is usually 250km/h then gradually increased to 320 km/h. Experiments have been conducted to confirm the effects were small and to adjust the related action loads (impact loads) considered in design by introducing correction factors. Some additional superficial settlements may take place below the rail track but can be handled by minor retrofitting works. So, there is basically no big influence and no change in the design methodology for higher running speed, but rigorously, relevant impacts loads in relation with this speed should be considered in design.

【5】 Not identified

Q: What is the cost ratio of reinforcement (geotextile) to overall cost?

What kind of geotextiles are typically used in RRR in Japan?

Tatsuoka: The cost of geotextiles only is roughly 15% of the total cost of the structure. (after confirmation, this figure was corrected from the value initially orally stated of 5%).

The use of proper geogrid reinforcement is of paramount importance for the successful construction of RRR structures. Since the full height rigid facing is constructed by casting-in-place fresh concrete on the self standing reinforced embankment which is constructed first, then reinforcements (geotextile) are in direct contact with fresh concrete and became firmly connected to it, so that a high alkaline resistance against high PH is primordial. This can be

achieved by polyvinyl alcohol products (PVA, vinylon) or high density polyethylene or polypropylene (HDPE, HDPP) materials. PVA is more expensive but has stronger resulting connection strength with concrete, while being more flexible and workable, with biaxial products readily available. HDPE is cheaper but usually uniaxial, less flexible and less workable.

For RRR retaining walls, PVA and HDPE are almost equally used in Japan, but for more critical structures such as RRR bridge abutments usually sided with RRR walls, PVA is almost solely used due to the advantages mentioned above.

It should be noted that PVA or HDPE products are in principle not exclusive to the RRR design. Any proper material that satisfies the required criteria (high alkaline resistance being one of them) can be used if their satisfactory performance is certified independently by the Railway Technical Research Institute RTRI Japan which conducts a series of experimental tests for this aim.

【6】 Mr. Suthar (NHSRCL)

Q: Is PVA available in India?

Tatsuoka: The PVA yarn raw material is to our knowledge only produced in Japan by Kuraray, but is usually shifted to other countries where PVA geotextile products can then be produced domestically. This is the case in Germany and other countries as well. Also in India, PVA products can be produced by TechFab India which has a collaboration with Kuraray.

<https://www.techfabindia.com>

【7】 Mr. Suthar (NHSRCL)

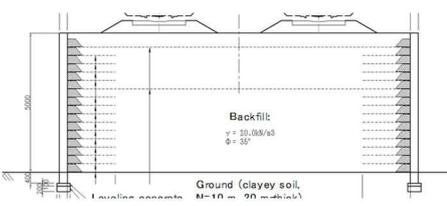
Q: What is the situation about the construction of conventional RWs or other reinforced RWs for railways in Japan?

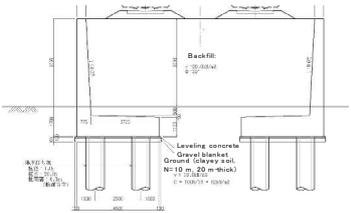
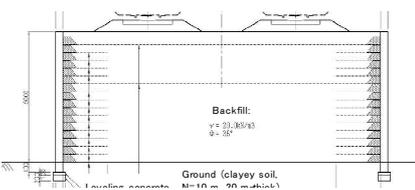
Q: Cost estimate shall be performed for this particular project, including cost differential with other conventional structure designs.

Tatsuoka: For newly constructed RWs for railways in Japan, nearly 100 % is RRR GRS RWs so the construction of conventional RWs or other reinforced RWS is nearly zero. The reason is that RRR GRS structures show better performance and also better cost effectiveness than conventional soil retaining structures and other types of reinforced soil structures. Cost estimate which includes not only the construction cost but also maintenance cost (that is the life cycle cost) have been made for typical design cases. It shows that RRR structures are approximately 20% cheaper than conventional cantilever structures in the absence of pile

foundation, and more than 65% (after confirmation, this figure was corrected from the value initially orally stated of 50%) in the case where pile foundation is necessary for conventional design. I believe the estimate has been also made for India high speed freight rail design project and that the ratios were roughly the same. Details can be given to Best Geotechnics Pvt. Ltd, so that they can perform a detailed cost estimate for this particular project using the most relevant and recent Indian market unit prices.

(for reference, as of 2015)

		Conventional type RW (L-shaped RC)	RRR GRS RW
<u>Dimensions</u>			
Height: 5.0 m Width: 13.5 m Length: 100 m		See Fig. 2-1 on the nex page for the details	The same as GRS RW in Fig. 1-2 for case 1.
<u>Remarks</u>		1. The relative cost changes with dimension changes. The GRS RW becomes more cost-effective than the conventional type RW as the wall becomes taller. 2. RRR GRS RW in this case is the same as the one in case 1 (Table 1)	
Construction cost (yen) <ratio>	Per 100 m	¥ 70,282,483 <1.00>	¥ 58,874,670 <0.84>
	Per 1 m	¥ 702,825/m	¥ 588,747/m
Track maintenance cost for 20 years (yen) <ratio>		¥10,963,170 <1.00>	¥5,481,585 <0.5>
Total cost <ratio>		¥ 81,245,653 <1.00>	¥ 64,356,255 <0.79>
Total cost-effectiveness		Low	High

		Conventional type RW (L -shaped RC)	RRR GRS RW
<u>Dimensions</u>			
Height: 5.0 m Width: 13.5 m Length: 100 m		See Fig. 1-1 on the next page for the details	See Fig. 1-2 on the next page for the details
<u>Remarks</u>		1. The relative cost changes with dimension changes. The GRS RW becomes more cost-effective than the conventional type RW as the wall becomes taller.	
Construction cost (yen) <ratio>	Per 100 m	¥ 179,806,785 <1.00>	¥ 58,874,670 <0.33>
	Per 1 m	¥ 1,798,068/m	¥ 558,747/m
Track maintenance cost for 20 years (yen) <ratio>		¥ 10,963,170 <1.00>	¥ 5,481,585 <0.5>
Total cost <ratio>		¥ 190,769,956 <1.00>	¥ 64,356,255 <0.34>

The second reason is that the use of a full-height rigid facing in RRR GRS structures, which is one of the most essential structural components for structure stability, allows also to support auxiliary structures which are various and important for railways, such as noise barriers, wind barriers, electric poles and so on, and ultimately a bridge girder. That actually led to the development of RRR bridge abutments. It should be emphasized that there is merely no relevant serious alternatives to RRR structures for bridge abutments. Conventional retaining structures or other reinforced structure technologies using for example metallic reinforcements or discrete panel facings or modular block facings cannot objectively achieve a stability or performance sufficient for such critical structures. Rusting and others issues are inherent problems for metallic reinforcements, discrete panel facings and modular block facings are prone to excessive deformation, very sensitive to scouring at the wall base and/or to single panel failure that endangers the whole structure stability. This cannot be accepted for railways. Bridge girder or other auxiliary structures need also separate foundation works in such cases. For the same reason, a setback is needed and trains cannot run close to the wall face, which drastically increases structure width, land use and land acquisition cost.

【8】 Best Geotech Pvt

Q: Construction management control shall be considered necessary after delivery of design. Don't you agree?

Kosaka: We confirm that the International Association of RRR construction system and IGI are ready to participate in the support for construction management control in this project, when relevant.

Tatsuoka: Similarly as for the current India high speed rail line with L&T and T-CAP, it is necessary for the main constructor of this project to fully understand the key construction procedures and the key features of the RRR structures. If the constructor is different from L&T and T-CAP, we will need to start explanation again from zero, that may require some work.

【Postscript】

We welcome any opportunity to clarify further what we have not been able to explain sufficiently today. We are always ready to do so.

I-4-3 Response to inquiry3

Notes complementing the contents of TS (proposed version)

The following complementary notes on the five items among those described in TS were prepared for the relevant execution of the construction of RRR GRS structures. In each item, the related contents of TS are summarized as necessary and the *[complementary note]* is presented in the *italic type*.

1. Reconfirmation of the compaction control of backfill for the GRS retaining walls (Notes complementing the contents of TS 4.4.2.3 Table-14)

The following four criteria should be satisfied as one body:

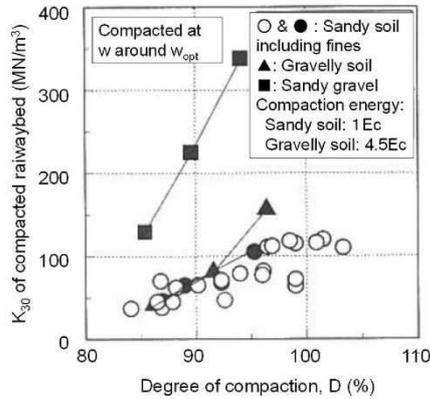
- 1-1) The performance rank I is required for the upper backfill supporting RC slab tracks. Then, according to Table 14 of “4.4.2.3 Criteria for backfill” of TS, it is required that, basically, each value of the degree of compaction is at least 95 % and the average is at least 92 %.

According to IS 2720 (Part 8), the maximum dry density to calculate the degree of compaction is obtained by laboratory compaction tests using the compaction energy of Modified Proctor.

- 1-2) According to Table 14 of “4.4.2.3 Criteria for backfill” of TS, it is required that, basically, each value of K_{30} is at least 70 MN/m³ and the average is at least 110 MN/m³.

- 1-3) According to Cause 4.2.1, the required type of backfill material is Group A.

[Complementary note] It is indicated in the figure shown below that the K_{30} values obtained with G class backfill are generally much higher than those with S class backfill when compacted at water content around the respective optimum water content. In case it is found that it is difficult to obtain the required values of K_{30} cited in Item 1-2) above with S class backfill, this problem could be alleviated by using relevant G class backfill. Although the K_{30} value of S class backfill may increase considerably by decreasing the water content from the optimum water content, the K_{30} value could decrease considerably from such a high value as above by wetting during a period of service of the railway. So, the compaction at water content that is excessively lower than the optimum water content is not allowed, as described in Item 1-4) below.



Appendix Fig.33.17: Relationship between K_{30} and D value for railwaybed backfill

“Railway Technical Research Institute, Japan (2007): Design Standards for Railway Structures and Commentary (soil structures), Railway Technical Research Institute, Appendix 33, pp. 434 (in Japanese)”.

- 1-4) With respect to the appropriate range of water content in soil compaction, according to Clause 4.3.3, 8., the water content range of backfill material shall be set to satisfy Clause 4.4.2.3 of this specification based on Clause 4.4.1.1. Moreover, according to Clause 4.3.2 on Backfill Banking Test, the contractor shall submit the “Banking Rule and Basis” in order to get desired degree of compaction specified in the Drawings which includes permitted range of appropriate water content.

[Complementary note] Although a specific permitted range of appropriate water content is not indicated in TS and the drawings, in ANNEXURE IV 3.0 of Guideline No. GE: G-1*, it is noted that “experience shows that most suitable water content falls within a small range of 3% below to 1% above the OMC for most of the soil”.

*GUIDELINES FOR EARTHWORK IN RAILWAY PROJECTS, Guideline No. GE: G-1 (including correction slip no. 1), July, 2003, Geo-technical Engineering Directorate, Research Designs and Standards Organisation Manak Nagar, Lucknow – 11, Ministry of Railway, Government of India

For reference, the following is the related description about the appropriate water content range in soil compaction on page 133 of “Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures”.

Before spreading fill material at the compaction place, it should be confirmed that the water content (w) of the fill material is not lower by 3 % and not higher by 1 % than the optimum

water content evaluated by the standard laboratory compaction test using the compaction energy level (CEL) equal to Modified Proctor (4.5Ec), $[W_{opt}]_{4.5Ec}$, so that the maximum dry density with respect to water content, or a value close to that, is achieved in the field compaction controlled to be performed at a CEL of the order of 4.5Ec. To ensure that the compacted state is satisfactory, it should be confirmed that all the measured values of the degree of compaction, D_c , are at least the specified lower bound value (typically 95 %). D_c is defined as the ratio of the field dry density, ρ_d to the maximum dry density, $[\rho_{dmax}]_{4.5Ec}$, times 100 %.

2. Reconfirmation of the compaction control of backfill for the approach block of GRS bridge abutments

(Notes complementing the contents of TS 4.4.2.3 Table-15)

The following four criteria should be satisfied as one body:

- 2-1) The performance rank I is required for the upper backfill supporting RC slab tracks. So, according to Table 15 of "4.4.2.3 Criteria for backfill" of TS, it is required that each value of the degree of compaction is at least 95%.

According to IS 2720 (Part 8), the maximum dry density to calculate the degree of compaction is obtained by laboratory compaction tests using the compaction energy of Modified Proctor.

- 2-2) According to Table 15 of "4.4.2.3 Criteria for backfill" of TS, it is required that, basically, each value of K_{30} is at least 150 MN/m³.

- 2-3) According to Cause 4.2.1, the requirement for backfill material is Group A.

[Complementary note] (the same as the one for item 1-3) However, since it is mixed with cement, S class backfill of A group may also be used.

- 2-4) About the appropriate range of water content in soil compaction:

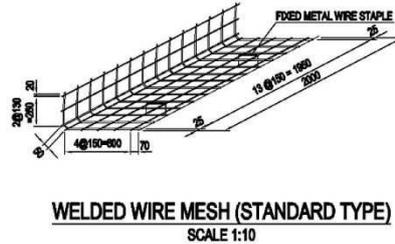
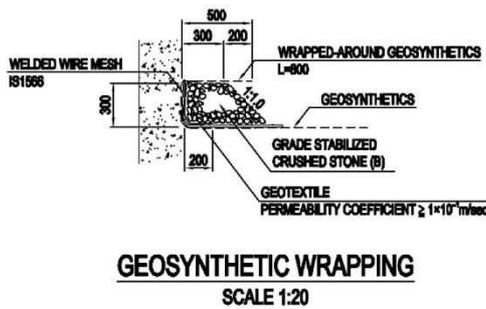
[Complementary note] (the same as the one for item 1-4) In short, the appropriate range of water content is between 3 % below and 1 % above the OMC determined by compaction tests using the compaction energy of Modified Proctor.

3. Construction details of GRS retaining walls and GRS bridge abutments
(Notes complementing the contents of TS 4.3.3, 4.3.4)

The followings are the complementary notes prepared to ensure successful construction of geosynthetic-reinforced backfill and full-height rigid RC facing for GRS retaining walls and GRS bridge abutments.

[Complementary notes]

3-1) *The temporary facing unit of welded wire mesh described in the figure below should be placed on the shoulder of each soil layer when constructing geosynthetic-reinforced backfill. The details of this temporary facing unit are described in Section [3.2.6 Temporary holding at the wall face] (pages 105 - 111 in “Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures”).*



Welded steel mesh for temporary holding of the backfill (“Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures”)

3-2) *The cement-mixed backfill for the approach block of GRS bridge abutment should be compacted in the same day when the backfill is mixed with cement and water.*

3-3) *The full-height RC facing for GRS retaining walls and GRS bridge abutments should be constructed after having confirmed that most of the deformation and settlement of the backfill and the supporting ground caused by the construction of the geosynthetic-reinforced backfill has taken place.*

The RC facing is constructed by casting-in-place fresh concrete into a narrow vertical space between the outside concrete formwork anchored in the body of geosynthetic-reinforced backfill and the temporary vertical wall face covered with geosynthetic-reinforcement layers wrapping-around the temporary facing units. An inside concrete formwork covering the temporary vertical wall face should not be used so that the completed RC facing is firmly connected to both of: a)

all the geosynthetic reinforcement layers; and b) the temporary facing units of welded wire mesh that are wrapped around with geosynthetic reinforcement layers, which becomes an important structural component of the completed GRS structure.

(Reference; [3.2.8 RC Facing Work] of "Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures".)

4. Full scale test

(Notes complementing the contents of TS 4.3.2)

In Clause 4.3.2, it is specified that "backfill banking is to be conducted before the actual construction of earth retaining structure".

[Complementary note] *It is required to confirm the following items that are to be applied to the construction of GRS structures by performing a full-scale test and analysing the results of the test:*

- 1) Confirmation of the properties of the construction materials (including the geosynthetic reinforcement and temporary facing unit) that are to satisfy the requirements described in TS.*
- 2) Organization of detailed step-by-step construction procedure that follows the descriptions in TS.*
- 3) Confirmation of the smooth construction when following the procedures prepared in Step 2) above.*
- 4) Confirmation of the ranked performance of constructed structures, including the K_{30} value, the degree of compaction and the water content specified in TS and indicated in the complementary notes.*

5. Manual

(Notes complementing the contents of TS 1.2.6)

[Complementary note] *"Manual on Design and Construction of Geosynthetic-Reinforced Soil Retaining Wall" that is cited as one of the documents that are to be referred to in TS means "Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures."*

II. Third workshop [21-25 October 2024]
(In India with visiting GRS Bridge Abutment at C4-ES2)

II-1 Workshop agenda including the list of participants



JICA-NHSRCL-ADB-Institute-JARTS Knowledge Sharing Workshop (Hybrid)
Construction method and Quality Control of Geosynthetic-Reinforced Soil (GRS) structure for High-Speed Rail

Date: 23 & 24 October 2024

Time: 09:30 – 15:10 IST/ 13:00 – 18:40 JST

Venue: 23 Oct: Construction Site in C4 Package (Vapi)

**24 Oct: NHSRCL Office, Swastik Universal Building, Opposite Central Mall,
Dumas Road, Rundh Surat, Gujarat-395007**

Organizing Partners

Japan International Cooperation Agency (JICA)
National High-Speed Rail Corporation Limited (NHSRCL)
Asian Development Bank Institute (ADBI)
Japan Railway Technical Service (JARTS)

Supporting Partners

High Speed Rail Innovation Center (HSRIC)

Background

Quality control during the construction of civil works is crucial, more so for High-Speed Rail (HSR), to ensure the safety of operations and the durability of assets. In India infrastructure for transportation sector i.e. expressways, metro rail, suburban railways etc. are being constructed at a very fast pace. Indian government agencies and private sectors have gained lot of experience in dealing with challenges relating to ensuring quality control. If quality is not ensured during the construction stage, it may lead to reduction of the service life of the infrastructure, increase maintenance efforts and cost, decreases the reliability of the asset operations and increases waste generation in the system.

This knowledge sharing workshop on Construction method and Quality Control of Geosynthetic-Reinforced Soil (**GRS**) structure for High-Speed Rail is being organized at a very opportune time as GRS structure construction works on MAHSR are just started. This will provide an opportunity for exchanging knowledge among various stake-holders involved in design, construction, supervision and manufacturing of materials for RE wall from both India as well as Japan.

23 Oct 2024 - Field Trip	
Time (IST)	Agenda
9:00-11:30	Travel from Surat to Vapi construction site
11:30-13:30	Outline of the Construction Site (by L&T and TCAP) and Site Visit
13:30-14:45	Lunch
14:45-17:30	Travel back to Surat

24 Oct 2024 - Workshop	
Time (IST)	Agenda
9:30	Registration and Coffee
9:45	Opening Ceremony
9:50-10:05	Inaugural Session
	9:50-9:55 1. Inaugural Remarks 1: Mr. Vivek Kumar Gupta (Managing Director NHSRCL)
	9:55-10:00 2. Inaugural Remarks 2: Mr. Takuro Takeuchi (Chief Representative, JICA India Office)
	10:00-10:05 3. Inaugural Remarks 3: Mr. Itsuki Koshiishi (Vice President, JARTS)
10:05-11:35	Session 1: Experience in Japan
	10:05-10:10 Introduction of the Chair and Session Speakers Session Chair: Mr. Yoshihiro Kumamoto, JICA Expert
	10:10-10:25 Expert Presentation 1: Development of RRR and Its Application in Japan Session Presenter 1: Dr. Susumu Nakajima (Laboratory Head, RTRI)
	10:25-10:40 Expert Presentation 2: Construction and Precautions for Reinforced Embankments in Japanese Shinkansen (Tentative) Session Presenter 2: Dr. Shin-ichi Tamai (Director-General for Railway Technology, JRRT)
	10:40-10:55 Expert Presentation 3: Key Construction Procedures for RRR-GRS Retaining Walls and Bridge Abutments (Tentative) Session Presenter 3: Mr. Takuya Kosaka (Chief Secretariat, International Association of RRR Construction System)
	10:55-11:10 Expert Presentation 4: Maintenance of Earthworks and Disaster Prevention Session Presenter 4: Mr. Itsuki Koshiishi (Vice President, JARTS)

	11:10-11:25	Expert Presentation 5: Disaster prevention measures for earth structure sections at JR East Session Presenter 5: Mr. Satoshi Takisawa (Manager, Structure Engineering Center, JRE)
	11:25-11:35	Q & A
11:35-11:45	Coffee break	
11:45-13:00	Session 2: Experience in India	
	11:45-11:50	Introduction of the Chair and Session Speakers Session Chair: HL Suthar (Principal Executive Director/Track & Design, NHRCL)
	11:50-12:05	Expert Presentation 1 Session Presenter 1: Dr. G. Venkatappa Rao (Visiting Professor, IIT Gandhi Nagar, Chairman, Geosynthetics Technology Advisory Services LLP, Jaipur, India Former Professor & Head, Dept of Civil Engineering, and Dean, Indian Institute of Technology Delhi, India)
	12:05-12:20	Expert Presentation 2 Session Presenter 2: TBA (NHRCL)
	12:20-12:35	Expert Presentation 3 TBA (L&T)
	12:35-12:50	Expert Presentation 4 TBA (TCAP)
	12:50-13:00	Q & A
13:00-14:00	Lunch Break	

14:00-15:00	Interaction Session	
	14:00-15:00	Open Discussion on issues on the Earth Structure <ul style="list-style-type: none"> • Session Chair: Dr. K.E Seetha Ram (Senior Consulting Specialist, ADBI; Visiting Professor, The University of Tokyo) • Invited Discussants: <ul style="list-style-type: none"> ○ Dr. Rao (IIT) ○ Dr. Shinichi Tamai (JRRT) ○ Dr. Susumu Nakajima (RTRI) ○ Mr. Itsuki Koshiishi (JARTS) ○ Mr. Satoshi Takisawa (JRE) ○ Mr. Noriaki Ebii (RRR-I) ○ Mr. HL Suthar (NHRCL) ○ TBD (TCAP) ○ TBD (L&T) *Interaction Session
15:00-15:10	Closing Remarks: Director Project, NHRCL or Director Works, NHRCL Dr. KE Seetharam on behalf of Dr. Byungsik Jung (Deputy Dean, ADBI, Tokyo)	

Itinerary for Site Visit of RRR Workshop Construction site

Date	21st October, Mon		22nd October, Tue		23rd October, Wed		24th October, Thu		25th October, Fri		26th October, Sat	
	Time	Event	Time	Event	Time	Event	Time	Event	Time	Event	Time	Event
AM	8:30	Haneda Airport Terminal 3 Meet in front of South Wing F Counter on Departure Level 3F	7:30	Hotel Check-out	8:30	Hotel Check-out by Car	8:30	Hotel Check-out by Car	8:30	Hotel Check-out by Car	6:20	Arrival at Haneda Airport (Disbandment)
	10:40	Departure from Haneda (JL039 Flight)	10:00	Air India Express	11:30	Visit to RRR construction-site	9:30	Start of Workshop				
Lunch			12:00	Arrival at Surat Airport	13:30	Discussion at Site			12:00	Hotel Check-out by Car		
					14:00	Lunch in Vapi	13:00	Lunch at Workshop site				
PM									14:00	Sightseeing by Car		
	16:30	Arrival in Delhi (IST)	14:30	Visit to Surat Station (Track construction, Training facilities)			15:10	End of Workshop by Car	16:00	Arrive at Surat Airport		
	17:30	Leave from the Airport (by Car)					16:00	Departure from Surat Airport	16:00	Arrival at Delhi Airport		
Dinner	18:00	Hotel Check-in Social Gathering	18:00	Hotel Check-in Free	18:00	Hotel Check-in Free	20:00	Hotel Check-in Social Gathering	19:05	Departure from Delhi (JAL030 Flight)		
Stay		Pride Plaza		Marriot Surat		Marriot Surat		Pride Plaza		on Board		

List of participants

NO.	Name	Organization	Possition	Remark
1	G. Venkatappa Rao	IIT		Presenter
2	Shinichi Tamai	JRTT		Presenter
3	Susumu Nakajima	RTRI		Presenter
4	Satoshi Takizawa	JRE		Presenter
5	Takuya Kosaka	RRR-I Association		Presenter
6	Tomoki Kuraoka	JRE		Attendee
7	Yasuyuki Kawanakajima	JRTT		Attendee
8	Noriaki Ebii	RRR-I Association		Attendee
9	Duttine Antoine	RRR-I Association		Attendee
10	Hajime Yoshida	JIC		Attendee
11	Vu Nhat Linh	JIC		Attendee
12	Shinji Morimoto	JICA		Host
13	K. E. Seetharam	ADB		Host
14	Itsuki Koshiishi	JARTS		Host
15	Vivek Kumar Gupta	NHSRCL		Host
16	H L Suthar	NHSRCL		Host
17	Yoshihiro Kumamoto	JICA Expert		Host
18	Koji Takano	JICA Expert		Host
19	Anil Khare	JRE		Assistant
20	Ms. Ryoko Nakano	JRE		Assistant
21	Sri Satish Chourasia	NHSRCL	CPM/Vasai	
22	Sri Seemanchal Padi	NHSRCL	JGM/Mumbai	
23	Sri G V Dahake	NHSRCL	DGM/Civil	
24	Sri Vipin Kumar Bansal	NHSRCL	SrMgr Design	
25	Dr. Amit Prashant	IIT-Gandhinagar	Professor	
26	Dr. Kolli Mohan Krishna	IIT-Gandhinagar	Research Associate	
27	Prof. Murali Krishnan	IIT-Tirupati	Professor	
28	Mr. Pranav Kumar	DRA, D-1 Package	VP Technical	
29	Mr. Keshav Rao	TCAP (PMC-Civil)	Chief Geotechnical Engineer	
30	Mr. Sanjay Bhargava	TCAP (PMC-Civil)	Chief Resident Engineer	
31	Mr. Satish Naik	BGPL (Best-Geotech),	Director	
32	Ms. Annaluru Usha	L&T	DGM	
33	Mr. Rajkumar K	L&T	JGM	
34	Mr. Akhilesh Kumar Singh	L&T	Sr Const Mgr	
35	Mr. Noriyuki Kurihara	JIC	Adovisor	
36	Dr. Fumio Tatsuoka	RRR-I Association	Professor emeritus	
37	Mr. Yukihiko Tamura	RRR-I Association	President	

※) In addition, other local consultants, contractors and NHSRCL staff will participate

※) Web cast will be available.

II-2 Pictures at construction site and workshop





II-3 PPT presentations

II-3-1 Susumu Nakajima (Railway Technical Research Institute)

JICA-NHSRCL-ADB-IARTS Knowledge Sharing Workshop (Hybrid)
 Construction method and Quality Control of Geosynthetic Reinforced Soil (GRS) structure for High Speed Rail
 24 October 2024, 09:30 - 16:00 (IST) 13:00 - 19:30(IST)

Outline and matters necessary to achieve sufficient performance of Geosynthetic Reinforced Soil structures for high-speed railway

Susumu Nakajima
 E-mail: nakajima.susumu.99@rtri.or.jp
Laboratory head of foundation and geotechnical engineering laboratory
 Railway Technical Research Institute, Japan

Contents of presentation from Japan

1. Outline and matters necessary to achieve sufficient performance of Geosynthetic reinforced soil structures for high-speed railway in Japan (Nakajima, RTRI)
2. GRS structures along latest SHINKANSEN (Dr. Tamai of JRTT)
3. Key construction procedures and their execution for successful construction of GRS retaining walls and GRS bridge abutment (Mr. Kosaka of RRR-I)
4. Disaster prevention measures for earth structure sections at JR East (Mr. Takisawa of JR-East)

We hope the presentations from Japanese members contribute to share Japanese experience for the sake of successful construction of Mumbai - Ahmedabad high speed train.

Contents of this presentation

1. Geosynthetic-Reinforced Soil Structures used in high-speed rail in Japan
2. Features of GRS retaining wall and GRS bridge abutment
3. Matters necessary to achieve sufficient performance
 - i. Staged construction
 - ii. Quality control of embankment and cement mixed approach block
 - iii. Material regulation
4. Summary

Geosynthetic-Reinforced Soil Structures used in high-speed rail in Japan

The diagrams illustrate three types of GRS structures:

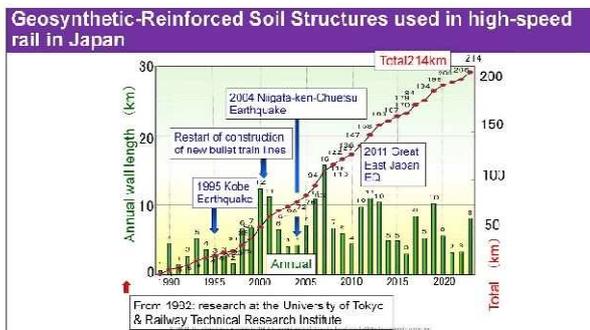
- RRR-GRS retaining wall:** Shows a cross-section with a concrete facing (sheet pile), reinforcement layers, and a backfill of cement-mixed gravelly soil. It includes labels for 'Connected', 'RC facing (sheet pile)', 'Reinforcement', 'Geogrid', and 'Unconnected backfill'.
- RRR-GRS bridge abutment:** Shows a cross-section with a 'Bridge girder' on top, 'Connected' reinforcement, 'RC facing (sheet pile)', 'Reinforcement', 'Geogrid', 'Cement mixed gravel reinforced with geogrid layers', and 'Unconnected backfill'.
- GRS Integral bridge:** Shows a cross-section with an 'Integrated girder and a pair of facing', 'Reinforcement', 'Geogrid', and 'Cement mixed gravelly soil'.

Geosynthetic-Reinforced Soil Structures used in high-speed railway in Japan

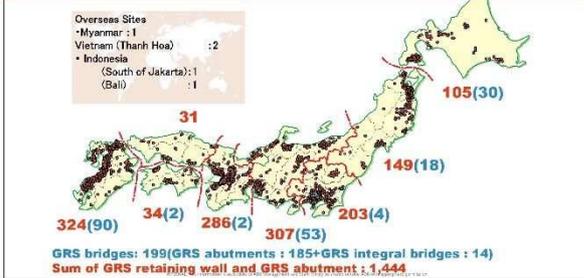
The diagrams illustrate three types of GRS structures:

- RRR-GRS Box culvert:** Shows a cross-section with a 'Box culvert' and 'Geogrid-reinforced compacted cement mixed gravelly soil (approach block)'. It includes labels for '(a) Geogrid-reinforced compacted cement mixed gravelly soil (approach block)', '(b) Backfill', '(c) Box culvert', and '(d) Connection separate'.
- RRR-GRS cut slope retaining wall:** Shows a cross-section with a 'Concrete wall facing', 'Geogrid', 'Cement mixed gravelly soil', and 'Ground'. It includes labels for 'Urethane mat Soil nailing', 'Concrete wall facing', and 'Ground'.
- RRR-GRS tunnel protection:** Shows a cross-section of a tunnel with 'Geogrid-reinforced compacted cement mixed gravelly soil' and 'Concrete wall facing'. It includes labels for 'Geogrid-reinforced compacted cement mixed gravelly soil' and 'Concrete wall facing'.

Nowadays GRS structures becomes to be the a tentative solution of the RC structures in Japan as be introduced by Dr. Tamai



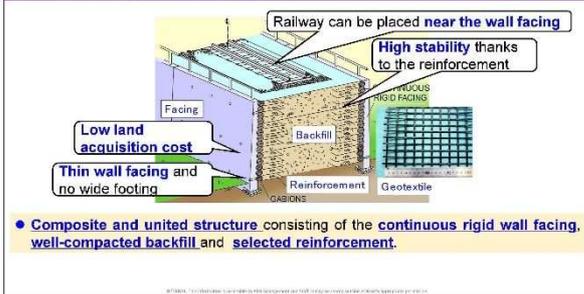
Geosynthetic-Reinforced Soil Structures used in high-speed rail in Japan



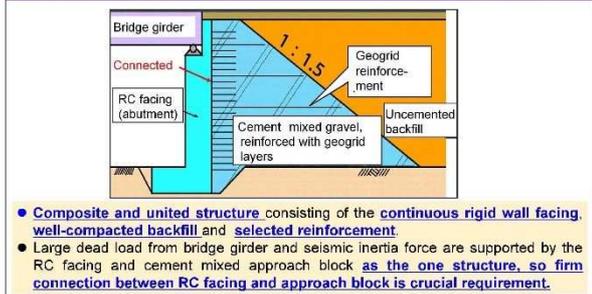
Contents of this presentation

1. Geosynthetic-Reinforced Soil Structures used in high-speed rail in Japan
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 - i. Staged construction
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 - iii. Material regulation
4. Summary

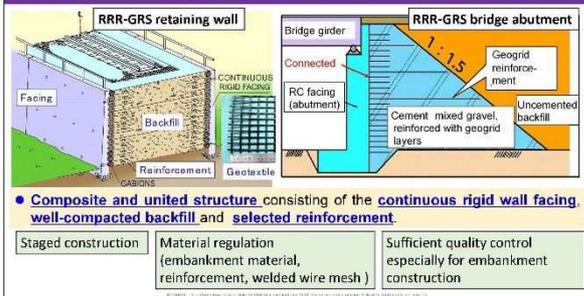
RRR-Geosynthetic-Reinforced Soil retaining wall



RRR-Geosynthetic-Reinforced Soil bridge abutment



Matters necessary to achieve sufficient performance



Contents of this presentation

1. Geosynthetic-Reinforced Soil Structures used in high-speed rail in Japan
2. Features of GRS retaining wall and GRS bridge abutment
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 - i. Staged construction
 - ii. Quality control of embankment and cement-mixed approach block
 - iii. Material regulation
 - ✓ Embankment material
 - ✓ Geosynthetics
 - ✓ Welded wire mesh
4. Summary

Why is staged construction necessary in GRS abutment and GRS retaining wall?

Outline of staged construction (Detail will be explained by Mr. Kosaka)

Foundation concrete on the stable stratum

Embankment or approach block construction up to full height

End of settlement

Rebar and formwork assembly

Cast in place concrete

By not assembling a formwork on the backside, fresh concrete can be also filled into the embankment, thus the wall facing and embankment are firmly integrated.

Cast in place concrete using formwork both front and backside -> Construction of embankment or approach block

Wall facing will be damaged by embankment deformation in the construction process, and more seriously, wall and backfill will behave separately. This situation is not assumed in design.

Why is material regulation needed? (1) Embankment material

Why is quality control needed?

- Only very small settlement is allowed both for backfill and subsoil.
- For required serviceability, total settlement after placing the slab track should be restricted less than 30 mm for the design life.
- For required serviceability, only 10 mm of consolidation settlement of the subsoil is allowed in 10 years.
- For required restorability, only 100 mm of residual settlement is allowed even after a massive earthquake.

Material regulations and compaction control standards, which are described in the specifications prepared for MAHSR project, must be correctly understood and operated. (Both embankment material regulation and quality control in Japan are explained by Dr. Tamai.)

Why is material regulation needed? (2) Geosynthetics

Item	General actions	Variable action during construction	Actions including Level 2 seismic load	Remarks
Standard tensile strength		T_k (kN/m)		determined taking into account variability
Material correction factor	$\rho_{m1} = 0.8$	$\rho_{m2} = 0.8$	$\rho_{m3} = 1.0$	
Characteristic tensile strength		$T_k = \rho_{m1} \cdot T_d$ (kN/m)		
Material factors	$\gamma_{m1} = 0.4-0.7$	$\gamma_{m2} = 0.6-0.95$	$\gamma_{m3} = 0.7-1.0$	Depending on types of action, with a obtained experimentally
Design tensile strength		$T_d = \gamma_{m1} \cdot T_k$ (kN/m)		

Why is material regulation needed? (2) Geosynthetics

Action combination	Reduction factors (○ : Considered)				
	α_1	α_2	α_3	α_4	α_5
Permanent action	○	○	○	—	—
Permanent action + variable action (train)	○	○	—	—	○
Permanent action + seismic action (L1 seismic ground motion) + secondary variable action	○	○	—	○	—
Permanent action + seismic action (L2 seismic ground motion) + secondary variable action	○	○	—	○	—
During construction	○	○	○	○	○

α_1 : Reduction factor considering alkaline resistance
 α_2 : Reduction factor related to damage during construction
 α_3 : Reduction factor related to creep
 α_4 : Reduction factor for momentary load
 α_5 : Reduction factor related to train load

Reinforcement are placed in high alkaline circumstance

Why is material regulation needed? (3) Welded wire mesh

The first function of welded wire mesh is a temporary holding to keep the embankment gradient vertical.

Large deformation will take place if the welded wire mesh is not strong enough against compaction load.

The other function of the wire mesh is to support the formwork from the reinforced embankment side through the L-shaped steel to prevent the formwork from deforming due to side pressure during cast in place concrete.

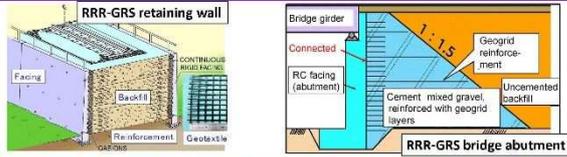
Concrete formwork may deform during cast-in place concrete execution, if the welded wire mesh is not strong enough against horizontal load.

To secure the desired shape at the completion of construction, it is important to select an appropriate temporal support material and to ensure the accuracy of the construction of the reinforced embankment.

Contents of this presentation

1. Geosynthetic-Reinforced Soil Structures used in high-speed rail in Japan
2. Features of GRS retaining wall and GRS bridge abutment
3. Matters necessary to achieve sufficient performance
 - i. Staged construction
 - ii. Quality control of embankment and cement-mixed approach block
 - iii. Material regulation
4. Summary

Summary



- **Composite and united structure** consisting of the **continuous rigid wall facing**, **well-compacted backfill** and **selected reinforcement**.
- Large dead load from bridge girder and seismic inertia force are supported by the RC facing and cement mixed approach block **as the one structure**.

Staged construction	Material regulation (embankment material, reinforcement, welded wire mesh)	Sufficient quality control especially for embankment construction
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Thank you for your kind attention!

Comments after site survey

Blank area for comments after site survey.

II-3-2 Shinichi Tamai (Japan Railway Construction, Transport and Technology)

鉄道運輸機構
JRTT

GRS Structures along Latest SHINKANSEN

JICA-NHSRCL-ADBI-JARTS Knowledge Sharing Workshop
Construction method and Quality Control of GRS structure for HSR
24 October 2024 Surat

TAMAI Shin-ichi
Japan Railway Construction,
Transport and Technology Agency (JRTT)



鉄道運輸機構
JRTT

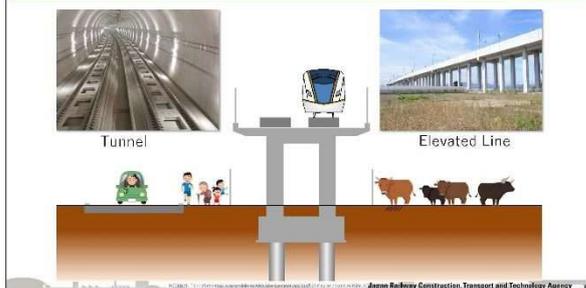
Today's Topics

- History of elevated lines and embankments in Japanese HSR
- Application of GRS structures
- How to build quality GRS structures

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Intrinsic Safety of SHINKANSEN



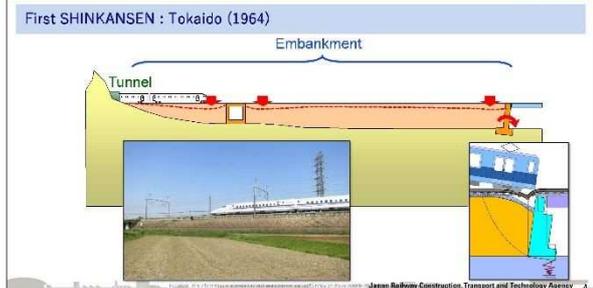
Tunnel Elevated Line

Japan Railway Construction, Transport and Technology Agency

鉄道運輸機構
JRTT

Construction of Elevated Lines 1G

First SHINKANSEN : Tokaido (1964)



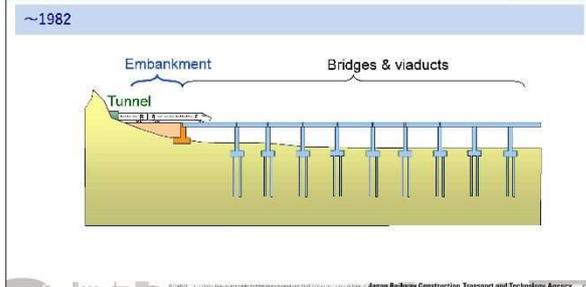
Tunnel Embankment Viaduct

Japan Railway Construction, Transport and Technology Agency

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JRTT

Construction of Elevated Lines 2G

~1982



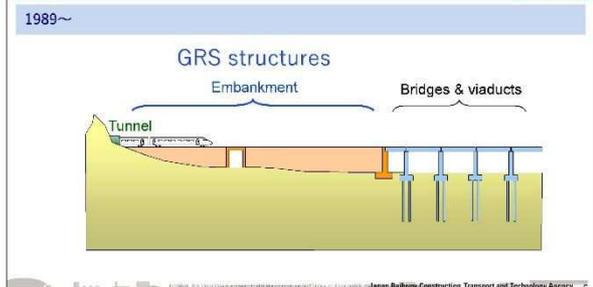
Tunnel Embankment Bridges & viaducts

Japan Railway Construction, Transport and Technology Agency

鉄道運輸機構
JRTT

Construction of Elevated Lines 3G

1989~



Tunnel GRS structures Embankment Bridges & viaducts

Japan Railway Construction, Transport and Technology Agency

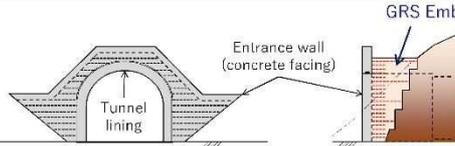
GRS Structures Around Tunnel Portal

- GRS Tunnel Entrance Protection
- Nail-Reinforced Soil (NRS) Retaining Wall



Japan Railway Construction, Transport and Technology Agency

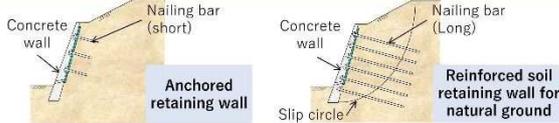
GRS Tunnel Entrance Protection




Japan Railway Construction, Transport and Technology Agency

NRS Retaining Wall

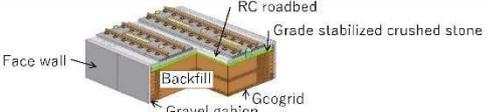
Nail Reinforced Soil (NRS)




Japan Railway Construction, Transport and Technology Agency

Elevated Line by GRS Structures

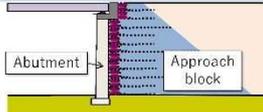
GRS Retaining Walls




Japan Railway Construction, Transport and Technology Agency

Elevated Line by GRS Structures

GRS Bridge Abutment



Approach block

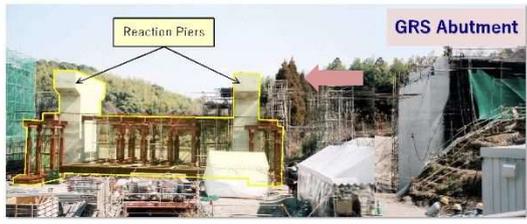
- lightly-cement-mixed gravelly soil
- reinforced by geogrid



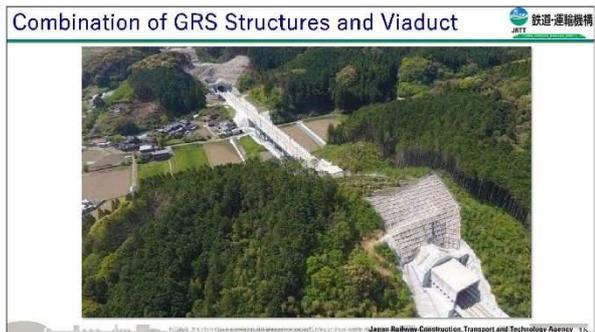
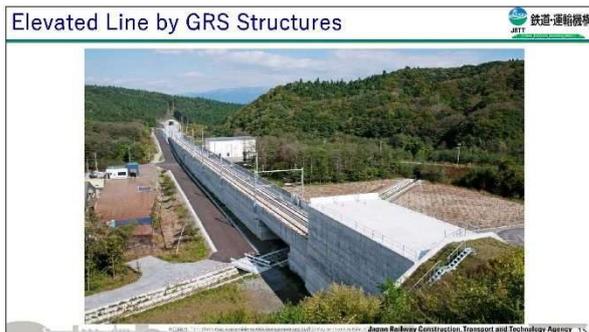
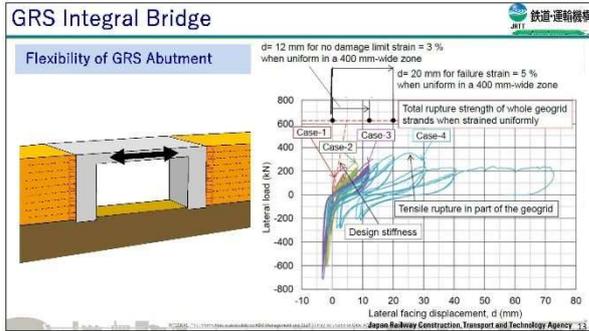
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GRS Abutments

Pulling test of actual GRS abutment



Japan Railway Construction, Transport and Technology Agency

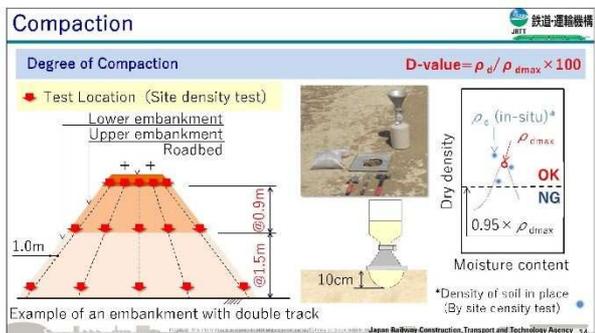
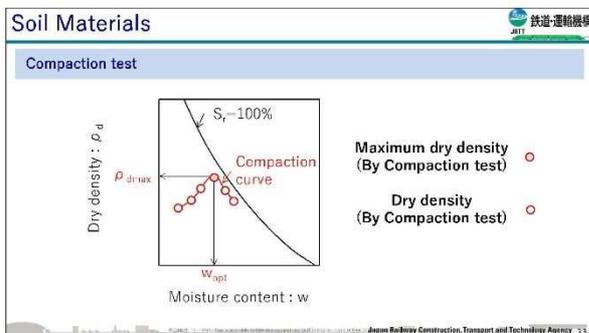
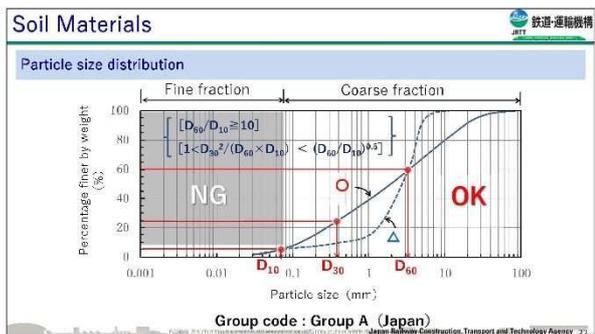
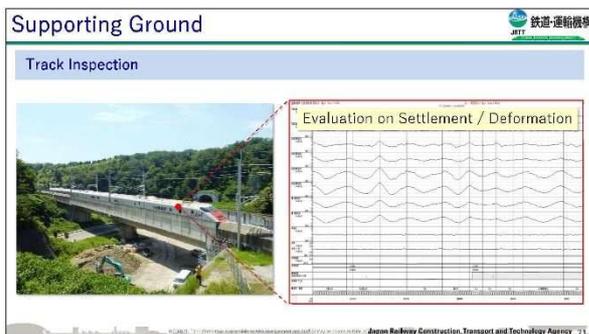
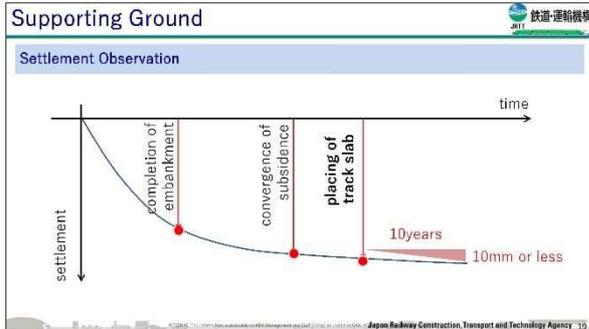


Requirements for a good embankment

Common regardless of reinforced or conventional embankment

Important	Supporting ground	Soil Materials	Compaction
Cement-stabilized approach block Materials: Grade stabilized crushed stone K_{30} -value*: 150MN/m ³ or more D-value*: 95% or more	Upper embankment Materials: Group A (gravel) K_{30} -value*: 110MN/m ³ or more D-value*: 95% or more		Lower embankment Materials: Group A (gravel) D-value*: 80% or more
	Supporting ground N-value (gravel, sandy): 20 or more (no risk of liquefaction) N-value (cohesive): 4 or more (adequate over consolidation under embankment load and no stability or settlement problems)		
	* Degree of compaction Examples of Performance Rank I (Japan)		

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Compaction

Degree of Compaction K₃₀-value

Test Location (Plate loading test)

Example of an embankment with double track

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Notes on GRS Structures

- To build a GRS bridge abutment, approach block just behind the abutment wall should be compacted well.
- Concrete wall should be casted after the confirmation of finalization of the settlement of the embankment.
- GRS that is body of embankment and concrete wall should be connected firmly.

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Notes on GRS Structures

Connection between GRS and concrete wall

Gravel gabion Geosynthetic

- 1) Leveling pad for facing
- 2) Placing geosynthetic & gravel gabions
- 3) Backfilling & compaction
- 4) Second layer
- 5) Completion of wrapped-around wall
- 6) Casting-in-place RC facing

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Notes on GRS Structures

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II-3-3 Takuya Kosaka (International Association of RRR Construction System)

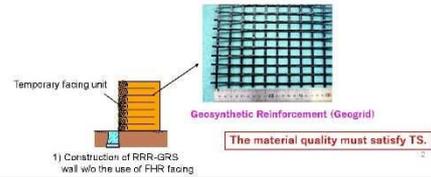
JICA-NHSRCL-ADBI-JARTS Knowledge Sharing Workshop (Hybrid)
 Construction method and Quality Control of Geosynthetic-Reinforced Soil (GRS)
 structure for High Speed Rail
 24 October 2024, 09:30 – 16:00 IST/ 13:00 – 19:30JST

Key Construction Procedures for RRR-GRS Retaining Walls and Bridge Abutments

International Association of RRR construction system (RRR-I)
 Chief Secretariat Takuya KOSAKA

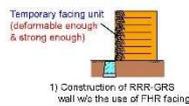
Five key construction procedures for RRR-GRS structures -1/5

- (1) The use of **geosynthetic-reinforcement (i.e., geogrid)** having a **high durability against high pH** (because of direct contact with concrete); and a **high pull-out strength** in the backfill and concrete, in addition to a **high rupture strength**.



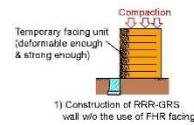
Five key construction procedures for RRR-GRS structures -2/5

- (1) The use of **geosynthetic-reinforcement (i.e., geogrid)** having a **high durability against high pH** (because of direct contact with concrete); and a **high pull-out strength** in the backfill and concrete, in addition to a **high rupture strength**.
- (2) The use of **temporary facing units** that satisfy **contradicting requirements**:
- flexible enough to accommodate** the deformation of the backfill and subsoil caused by the construction of the backfill; and
 - strong enough to be stable** against the earth pressure and compaction forces during wall construction.



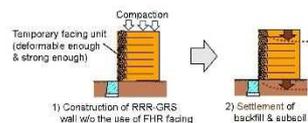
Five key construction procedures for RRR-GRS structures - 3/5

- (3) The use of backfill of **high quality; good compaction; and confirmation of high quality of compacted backfill**.



Five key construction procedures for RRR-GRS structures - 4/5

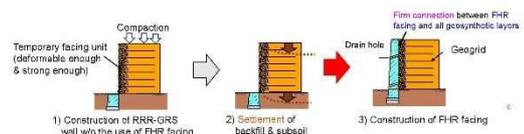
- (3) The use of backfill of **high quality; good compaction; and confirmation of high quality of compacted backfill**.
- (4) **Confirmation of sufficient settlement of the backfill** caused by its construction **before** the construction of RC facing (i.e., **staged-construction**).



Five key construction procedures for RRR-GRS structures - 5/5

- (5) The construction of **full-height rigid (FHR) facing** by **casting-in-place fresh concrete after** the end of the **settlement** of the backfill.

When constructing the FHR facing, **all the geosynthetic-reinforcement layers should be firmly connected to the back of the FHR facing**.



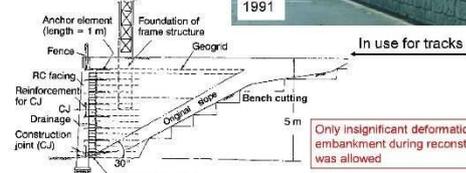
Construction of full-height rigid (FHR) facing after the construction of reinforced backfill

Depot for High Speed Railway (Shinkansen) at Biwajima, Nagoya, Japan, 1990 - 1991
 - average wall height= 5 m & total wall length= 930 m

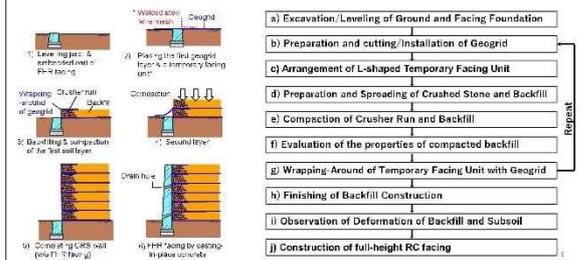


A typical RRR-GRS RW with FHR facing

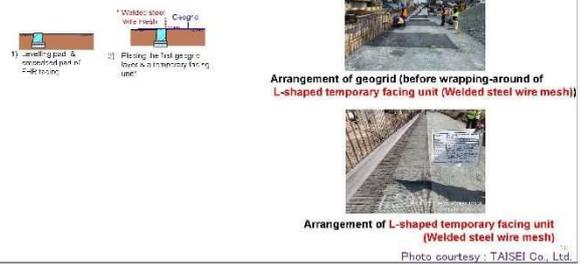
Re-construction of a gentle slope to a vertical wall for the depot of HSR (Shinkansen) at Biwajima, Nagoya



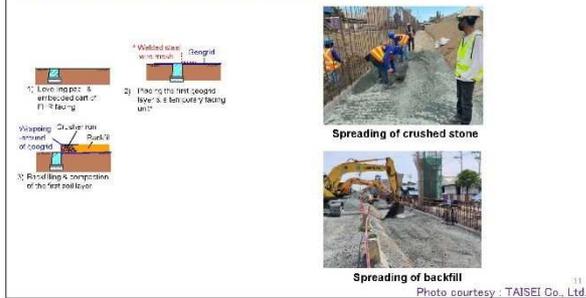
Construction procedures for RRR-GRS structures



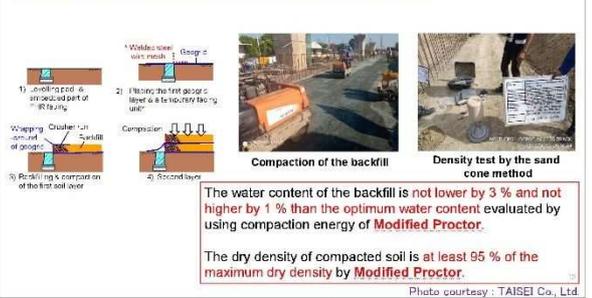
Six key construction steps for RRR-GRS retaining walls (1/6)



Six key construction steps for RRR-GRS retaining walls (2/6)



Six key construction steps for RRR-GRS retaining walls (3/6)



Six key construction steps for RRR-GRS retaining walls (4/6)

- Leveling pad & attached part of backfilling
- Backfilling & compaction of the first soil layer
- Completing GRS wall with FHR facing

Completed backfill, waiting for the end of the performance of backfill and subsoil

Six key construction steps for RRR-GRS retaining walls (5/6)

- Second layer
- FHR facing by adding in place concrete

Completed wall, (FHR RC facing), after the construction of FHR facing

Six key construction steps for RRR-GRS retaining walls (6/6)

- Completing GRS wall with FHR facing
- FHR facing by casting in place concrete

Note: the procedure is basically the same when using welded steel wire mesh in place of gravel bags as temporary facing units.

This steel rod is not a permanent member, not expected to function for wall stability.

Some fresh concrete enters the gravel-filled bags or welded steel wire mesh through the aperture of the geogrid.

⇒ Then, FHR facing & geogrid layers are firmly connected to each other.

Construction Procedures of RRR-GRS Bridge Abutment

- Shallow ground improvement when necessary

Construction Procedures of RRR-GRS Bridge Abutment

- Shallow ground improvement when necessary

Approach block of cement-mixed gravelly soil

Sufficient settlement of the backfill should have taken place before the construction of the RC abutment structure (i.e., FHR facing) that is firmly connected to the approach block

For High Speed Railway (Shinkansen) 13.4 m-high, Mantaro site, Hokkaido

Under construction Oct. 2011

Construction Procedures of RRR-GRS Bridge Abutment

- Shallow ground improvement when necessary

Firm connections

Step 4 (the construction of RC abutment structure (i.e., FHR facing) is after steps 2 & 3 (the construction of approach backfill).

For High Speed Railway (Shinkansen) 13.4 m-high, Mantaro site, Hokkaido

Under construction Oct. 2011

Construction Procedures of RRR-GRS Bridge Abutment

Step 4 (the construction of RC abutment structure (i.e., FHR facing) is after steps 2 & 3 (the construction of approach backfill)).

For High Speed Railway (Shinkansen)
13.4 m-high, Maniwa site, Hokkaido

1 Shallow ground improvement when necessary

Setting of bearing shoes

Under construction
Oct. 2011

Completed
Aug. 2012

Construction Procedures of RRR-GRS Bridge Abutment

Step 4 (the construction of RC abutment structure (i.e., FHR facing) is after steps 2 & 3 (the construction of approach backfill)).

For High Speed Railway (Shinkansen)
13.4 m-high, Maniwa site, Hokkaido

1 Shallow ground improvement when necessary

Setting of bearing shoes

No pile!

Under construction
Oct. 2011

Completed
Aug. 2012

What is Cement-mixed gravelly soil?

Cement-mixed gravelly soil is often used for important railway structures allowing a limited amount of deformation.

RC abutment structure and geosynthetic-reinforced cement-mixed gravelly soil are firmly connected to resist against girder lateral forces and earth pressures.

Soil backfill

Cement-mixed gravelly soil

Well-graded gravel (B class of Group A)

Bench-cutting

Adjustment of moisture content of backfill

Cement-mixing of backfill

Sample (1) of RRR-GRS Bridge Abutment under Construction completed 2020, Shimo-shinjo No. 1, Hokuriku Shinkansen

Scaffold frame

Cage of steel reinforcing bars

Approach block under construction

RC abutment structure completed by casting in-place fresh concrete after the completion of the approach block

Completed approach block

By the courtesy of Mr. Yonezawa, T., JRJT

Sample (2) of RRR-GRS Bridge Abutment under Construction Sugamuta viaduct, 2018

1. Bench-cutting of stable natural slope

2. Construction of geogrid-reinforced lightly cement-mixed gravelly soil

3. Compaction (@150mm height) and Compaction tests (@900mm height (3 layers)) of the backfill (at least 95% of $(P_u)_{max}$ and at w_{opt} by Modified Proctor)

By the courtesy of Mr. Soga, JRJT

Sample (2) of RRR-GRS Bridge Abutment under Construction Sugamuta viaduct, 2018

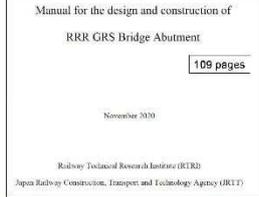
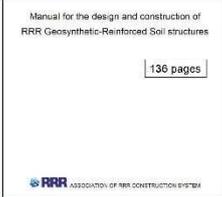
4. Arrangement of geogrid layer
(*Both the geogrid for the abutments and that for the approach blocks may be laid at the same time.)

5. Completed reinforced backfill (waiting until settlement of the backfill and subsoil has been stabilized)

6. Completed RRR-GRS Bridge Abutment after the construction of FHR facing (w/o inner formwork)
(*Constructing the RC abutment walls first makes it easier to set the external formwork for constructing the RC approach block walls.)

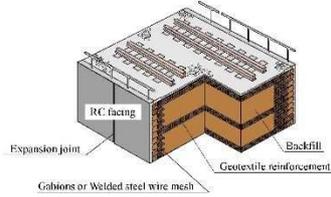
By the courtesy of Mr. Soga, JRJT

Two basic manuals (open documents)



These two manuals were prepared based on the experiences gained by the design, construction and maintenance of a large number of RRR-GRS structures for the last about 40 years, including many for High-Speed Railways in Japan. All the projects of RRR-GRS structures are successful, showing that the proper design and construction following these two manuals is the must for successful projects.

Illustration video of Staged Construction Procedure of RRR-GRS RWs

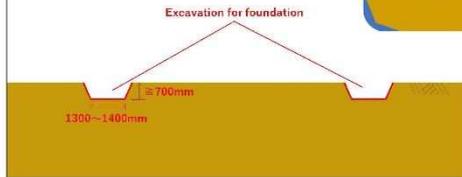


Before the start of construction



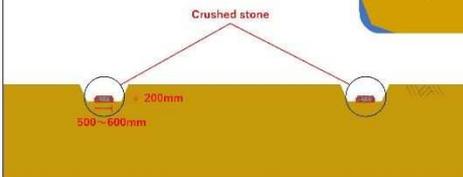
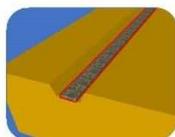
27

Foundation Work ① (Excavation for foundation)



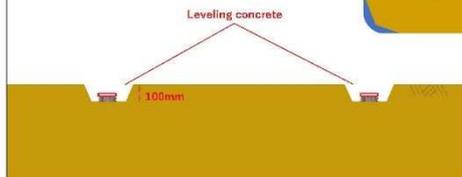
28

Foundation Work ② (Filling crushed stone)

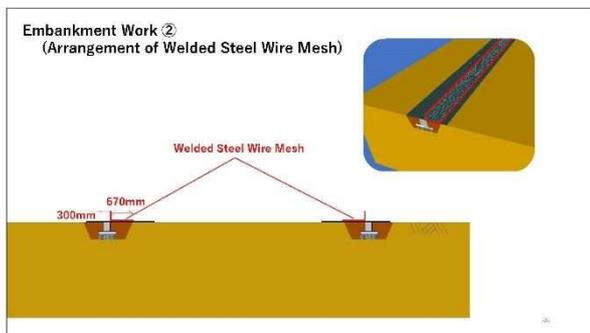
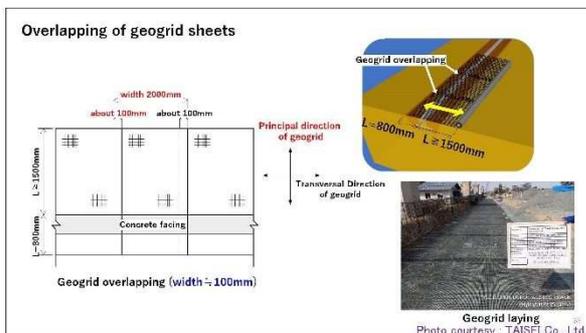
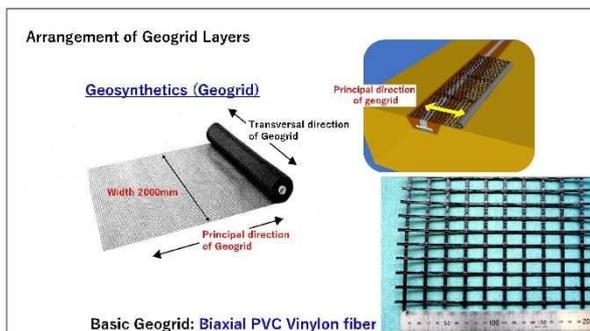
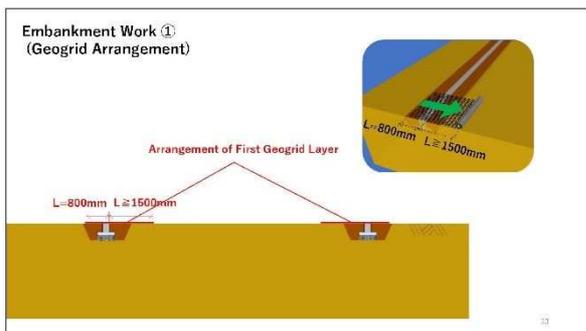
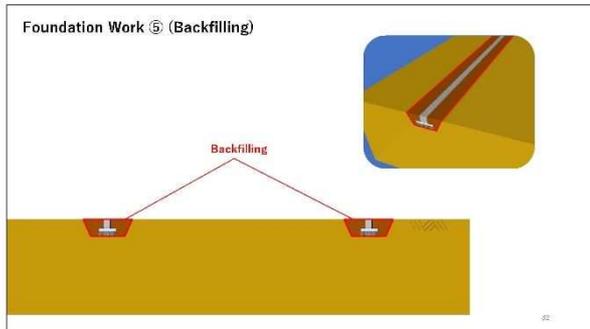
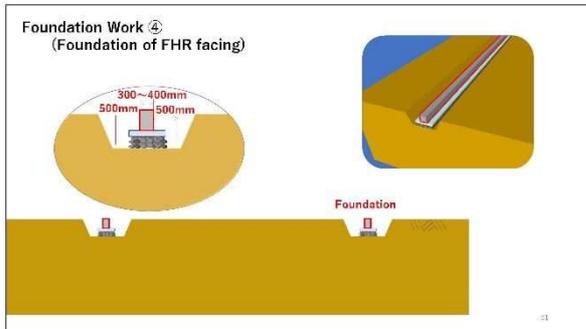


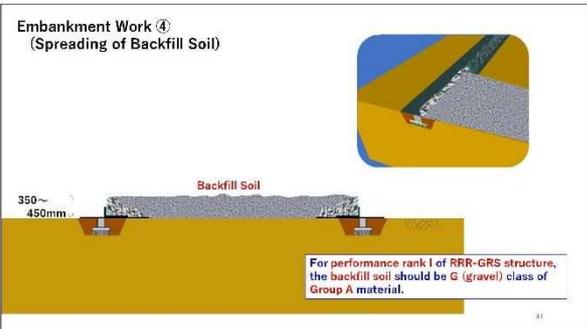
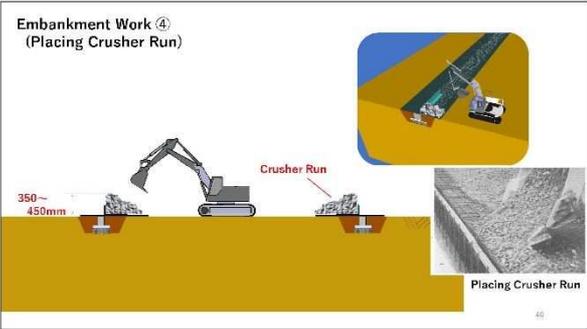
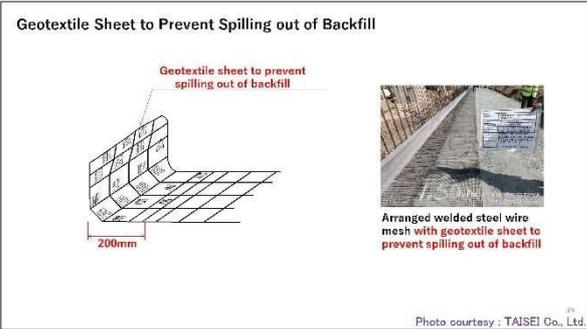
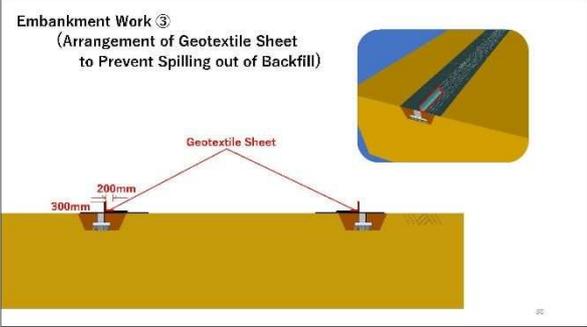
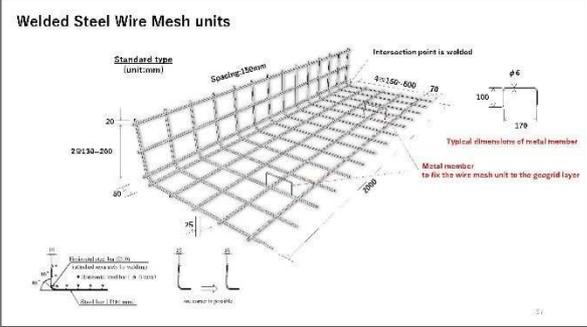
29

Foundation Work ③ (Leveling Concrete)



30





Embankment Work ⑤ (Compaction)

Hand-operated tamping
300mm
Heavy Machinery
Hand-operated tamping

The whole of each soil layer should be compacted at a single stage.

42

Appropriate compaction of the backfill

Hand-operated tamping
About 1.0m
Wall face
Geosynthetic

■ Compaction within about 1.0 m next to the wall face by hand-operated tamping.

Compaction of backfill soil by hand-operated tamping

44

Appropriate compaction of the backfill

Hand-operated tamping (width ≈ 1.0m)
Heavy machinery
Wall face
Geosynthetic

■ The compaction in the direction parallel with the wall face.
■ The start of compaction from the wall face side to deeper locations step by step.

Compaction of backfill soil by heavy machinery

Photo courtesy : TAISEI Co., Ltd.

45

Appropriate compaction of the backfill

Hand-operated tamping (width ≈ 1.0m)
Heavy machinery
Wall face
Geosynthetic

■ The compaction in the direction parallel with the wall face.
■ The start of compaction from the wall face side to deeper locations step by step.

Compaction of backfill soil by heavy machinery

Photo courtesy : TAISEI Co., Ltd.

46

Appropriate compaction of the backfill

Hand-operated tamping (width ≈ 1.0m)
Heavy machinery
Wall face
Geosynthetic

GOOD!

■ The compaction in the direction parallel with the wall face.
■ The start of compaction from the wall face side to deeper locations step by step.

Compaction of backfill soil by heavy machinery

Photo courtesy : TAISEI Co., Ltd.

47

Inappropriate compaction of the backfill-1

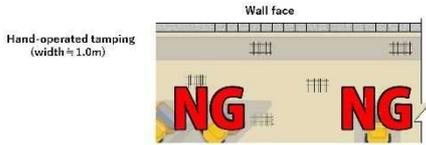
Hand-operated tamping (width ≈ 1.0m)
Wall face
Geosynthetic

■ The heavy machinery shall run in the direction parallel with the wall face.

Compaction toward the wall face may cause
① loosening of the geogric and
② the swelling out of the temporary holding at the wall face.

48

Inappropriate compaction of the backfill-1

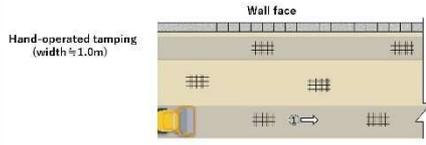


■ The heavy machinery shall run in the direction parallel with the wall face.

Compaction toward the wall face may cause:
 ① loosening of the geogrid and
 ② the swelling out of the temporary holding at the wall face.

49

Inappropriate compaction of the backfill-2

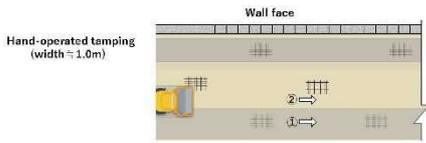


■ The compaction should start from the wall face side step by step.

Start of compaction from a deep side far away from the wall face will cause:
 ① loosening of the geogrid and
 ② the swelling out of the temporary holding at the wall face.

50

Inappropriate compaction of the backfill-2

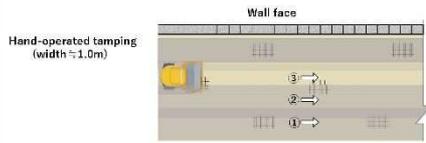


■ The compaction should start from the wall face side step by step.

Start of compaction from a deep side far away from the wall face will cause:
 ① loosening of the geogrid and
 ② the swelling out of the temporary holding at the wall face.

51

Inappropriate compaction of the backfill-2

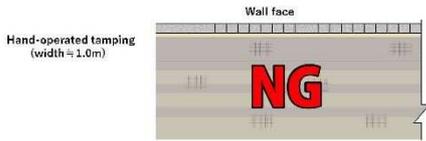


■ The compaction should start from the wall face side step by step.

Start of compaction from a deep side far away from the wall face will cause:
 ① loosening of the geogrid and
 ② the swelling out of the temporary holding at the wall face.

52

Inappropriate compaction of the backfill-2

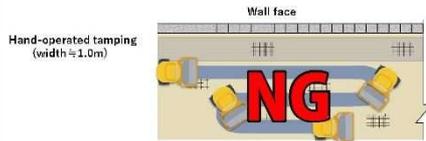


■ The compaction should start from the wall face side step by step.

Start of compaction from a deep side far away from the wall face will cause:
 ① loosening of the geogrid and
 ② the swelling out of the temporary holding at the wall face.

53

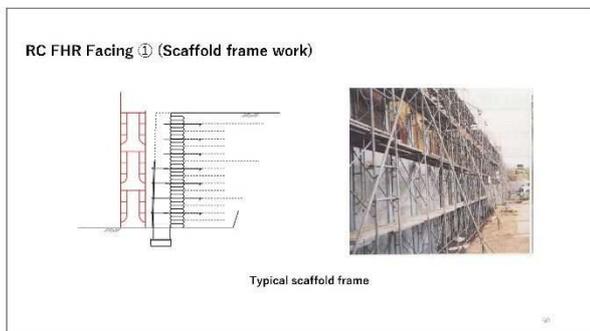
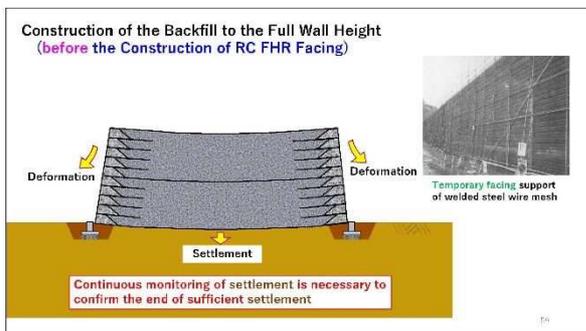
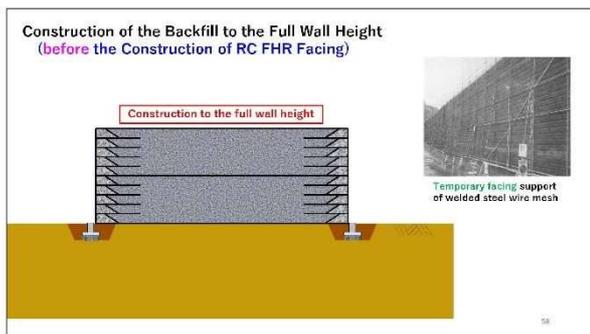
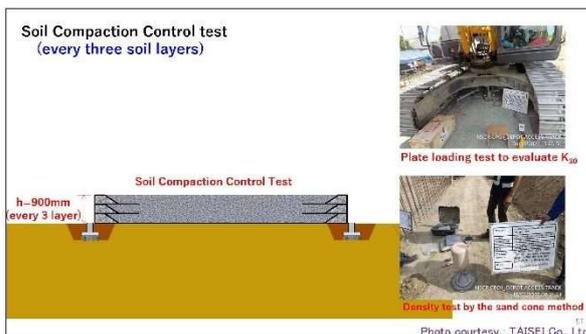
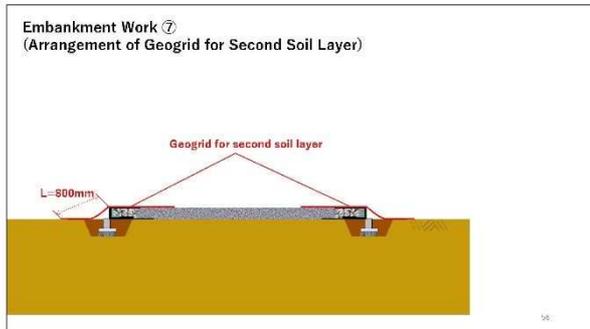
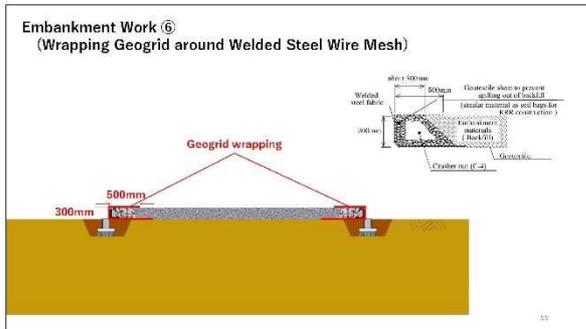
Inappropriate compaction of the backfill-3



■ Heavy machinery shall not be stopped or turned suddenly,

not to disturb the compacted backfill and the geogrid layers.

54



RC FHR Facing ② (External Form work) (w/o Inner form)

External concrete form

L-shaped steel member (more than L:5×40mm)

Vertically arranged L-shaped-steel member to which the separators to fix external concrete form are welded

Steel member to fix L-shaped steel member (ID=10mm)

Separator (φ=8mm)

Separator is welded to vertically arranged L-shaped steel member

Example of L-steel

For firm connections

Steel member for fixing L-shaped steel member

Typical method to arrange the steel member to fix L-shaped steel members

RC FHR Facing ③ (Drain work)

Drain pipe (φ95[standard])

Backfill

Socket (φ75)

Typical arrangement of drain pipe (Placed in one location every 2 to 4 m²)

Installation of drain pipes

RC FHR Facing ④ (RC facing work)

RC FHR facing by cast-in-place concrete

300~400mm

Drain Hall

Cast-in-place fresh concrete so that the welded wire mesh wrapped-around with the geogrid and the RC FHR facing are firmly connected.

Completed FHR facing

Photo courtesy: TAISEI Co., Ltd.

Completion

RC facing

Expansion joint

Backfill

Geotextile reinforcement

Gabions or Welded steel wire mesh

Completion of RRR-GRS Retaining Wall

Finally

"The Design and Construction Manual" and "the Illustration Video" for RRR-GRS Construction Method are available on the RRR-/ Association Website and can be freely downloaded.

<https://www.rrr-sys.gr.jp/en/>

Thank you for your kind attention

आपके ध्यान देने के लिए धन्यवाद

II-3-4 Itsuki Koshiishi (Japan Railway Technical Service)

<p>Maintenance of Earth Structures and Disaster Prevention</p> <p>24 Oct. 2024</p> <p>Itsuki KOSHIISHI</p>	<p>Characteristics of Earth Structures for Shinkansen</p> <div style="background-color: #0056b3; color: white; padding: 10px;"> <p>Percentage of Earth Structures in the Total Route Length</p> <table border="0"> <tr> <td>Tokaido Shinkansen (1964)</td> <td>approx.53%</td> </tr> <tr> <td>Sanyo Shinkansen (1975)</td> <td>approx.13%</td> </tr> <tr> <td>Tohoku & Joetsu Sinkansen (1985)</td> <td>approx.4%</td> </tr> <tr> <td>Other Shinkansen of JRE (1997~)</td> <td>approx.9% (increased)</td> </tr> </table> <p>⇒Maintenance of embankments on the Tokaido Shinkansen line was difficult. Improving reliability of earth structures through the development of RRR method, etc.</p> </div>	Tokaido Shinkansen (1964)	approx.53%	Sanyo Shinkansen (1975)	approx.13%	Tohoku & Joetsu Sinkansen (1985)	approx.4%	Other Shinkansen of JRE (1997~)	approx.9% (increased)
Tokaido Shinkansen (1964)	approx.53%								
Sanyo Shinkansen (1975)	approx.13%								
Tohoku & Joetsu Sinkansen (1985)	approx.4%								
Other Shinkansen of JRE (1997~)	approx.9% (increased)								

<p>Maintenance Issues related to Earth Structures①</p> <div style="background-color: #0056b3; color: white; padding: 10px;"> <p>Increasing Force (effect of Global Warming?)</p> <p>Increasing Rainfall Increasing Short-Time Heavy Rain } <u>“Water”</u></p> <p>Decreasing Bearing Force</p> <p>Progression of <u>“Weathering”</u> from Surface</p> </div>	<p>Maintenance Issues related to Earth Structures ②</p> <div style="background-color: #0056b3; color: white; padding: 10px;"> <p>Change of Surrounding Environment (Housing Development, Road Construction, Tree Cutting, etc.)</p> <ul style="list-style-type: none"> • Change of Drainage Condition <p>Impacts from <u>Third-Party Area outside Railway Land</u></p> <ul style="list-style-type: none"> • Necessary to Pay Attention to Such Area </div>
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<p>Key Points in Design & Construction of Earth Structures</p> <div style="background-color: #0056b3; color: white; padding: 10px;"> <p>Prerequisite: Civil structures are constructed according to the design (construction management, completion inspection)</p> <p>Nevertheless, pay attention to <u>the details of the design and construction.</u></p> <p>Viewpoint: Are drain routes and capacity appropriate? Are there any gaps that rainwater comes in?</p> </div>	<p>Measures to Prevent Accidents affecting Train Operation</p> <div style="background-color: #0056b3; color: white; padding: 10px;"> <p>① Regular Inspection by Site Office Engineers ② Types of Engineer Experts in a Particular Technical Field (usual) <u>Local experts who understand the changes in the local area over time</u></p> <p>③ Persistent Maintenance Dredging Drainage to Prevent Blockages caused by Trash and Waste, etc. Cutting Adjacent Trees Weed Control</p> </div>
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Special Requirement for Safe & Stable Shinkansen Operation

Shinkansen is a high-speed rail.
If an object strikes a Shinkansen train, there is a high possibility of a serious accident including derailment.
In Japan, impacts from objects weighing even a few hundred grams are considered problematic.
⇒Maintenance considering high speed operation is critical. (Strict maintenance is required compared to conventional lines.)

Basic Disaster Prevention for Earth Structures of Shinkansen

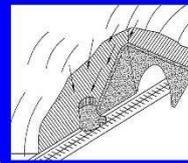
- Operation Regulation in Extreme Weather (Heavy Rain, etc.)
 - Speed Regulation
 - Suspension of Operation
- Install protective facilities + prevent soil from reaching the rails even if a landslide occurs.
 - Ensure enough distance from slopes
 - Protective fence as a double safety measure

Protective Fence as a Double Safety Measure

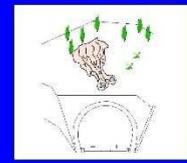


Concerned Incident about Shinkansen

Slope Failure aside of Tunnel Entrance



Slope Failure outside Railway Land above Tunnel Entrance



Example of "Good Job!"

Example (Conventional Line)

Cutting Slope Failure on 24 June, 1987

S62/6/24 上越線災害

How was this video filmed?

- How was this place paid attention to?
- Who was monitoring?
- How could the time of collapse be predicted ?
- How was the train operation suspended?

⇒ **Deployment of trained front-line engineers is crucial.**

It all starts with "**noticing a change**".

Then, request support of expert engineers.

Thank you for your attention!

II-3-5 Satoshi Takisawa (East Japan Railway Company)



Disaster prevention measures for earth structure sections at JR East

Structure Engineering Center, JR East
Satoshi Takisawa

Disaster prevention measures for earth structure sections at JR East

Three initiatives to protect railways from disasters

- Improving disaster resistance of structures → Strengthening disaster prevention measures
- Observe natural forces and restrict train operations when dangerous conditions arise → Operation restrictions
- Detecting the occurrence of a disaster and stopping trains before reaching the site → Disaster detection

Disaster prevention measures for earth structure sections at JR East

Operation restriction section for rain

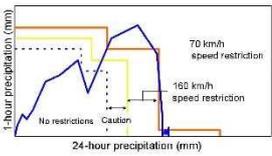


- Red line: Section with operator's subject on criteria
- Yellow line: Section with special restriction standards
- Blue line: Section with no special restriction

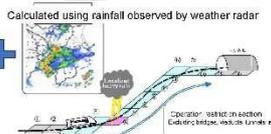
Disaster prevention measures for earth structure sections at JR East

Issuance and lifting of operation restrictions for rain [Shinkansen]

Since Aug. 2020
Introduction of regulation using radar-based rainfall



Calculated using rainfall observed by weather radar

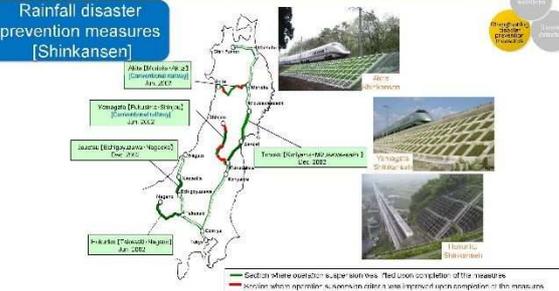


Operator's subject on section
Caution, brake, stop, turn etc.

Train operations suspended, when once-in-several-decades-rainfall is observed.

Disaster prevention measures for earth structure sections at JR East

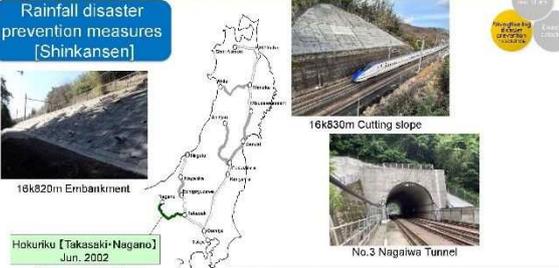
Rainfall disaster prevention measures [Shinkansen]



- Abiko (Tokaido-Shinkansen) Jun. 2012
- Yokohama (Tokaido-Shinkansen) Jun. 2012
- Maebashi (Tokaido-Shinkansen) Jun. 2012
- Yamanashi (Tohoku-Shinkansen) Oct. 2012
- Yokohama (Tohoku-Shinkansen) Oct. 2012
- Maebashi (Tohoku-Shinkansen) Oct. 2012

Disaster prevention measures for earth structure sections at JR East

Rainfall disaster prevention measures [Shinkansen]



Hokuriku [Takasaki-Nagano] Jun. 2002

Slope protection

Disaster prevention measures for earth structure sections at JR East

Rainfall disaster prevention measures [Shinkansen]

High energy absorbing protection net

Hokuriku [Takasaki-Nagano] Jun. 2002

Prevention of soil inflow and rockfall

Protective fence

— Section where operation suspension was lifted upon completion of the measures.
 — Section where operation suspension was lifted upon completion of the measures.

Disaster prevention measures for earth structure sections at JR East

Rainfall disaster prevention measures [Shinkansen]

404x590m Embankment

Tohoku [Koriyama-Mizusawaesashi] Dec. 2002

Slope protection

345x983m Cutting Slope

301x640m Oka Tunnel

— Section where operation suspension was lifted upon completion of the measures.
 — Section where operation suspension was lifted upon completion of the measures.

Disaster prevention measures for earth structure sections at JR East

Rainfall disaster prevention measures [Shinkansen]

426x575m Minowa Tunnel

High energy absorbing protection net

Tohoku [Koriyama-Mizusawaesashi] Dec. 2002

Prevention of soil inflow and rockfall

426x500m Iwamori Tunnel

High energy absorbing protection net

126x750m Protective fence

— Section where operation suspension was lifted upon completion of the measures.
 — Section where operation suspension was lifted upon completion of the measures.

Disaster prevention measures for earth structure sections at JR East

Rainfall disaster prevention measures [Conventional railway]

Slope protection

— Section where operation suspension was lifted upon completion of the measures.
 — Section where operation suspension was lifted upon completion of the measures.

Disaster prevention measures for earth structure sections at JR East

Landslide detection device

Conventional railway (Not Shinkansen)

Landslide detection device (Cut)

Landslide detection device (Embankment)

Wire switch type

Safety switch

Actuator

Wire clip

Safety switch

Safety switch activated

— Section where operation suspension was lifted upon completion of the measures.
 — Section where operation suspension was lifted upon completion of the measures.

Disaster prevention measures for earth structure sections at JR East

Rockfall detection device

Conventional railway (Not Shinkansen)

Wire switch type

Safety switch

Actuator

Wire clip

Safety switch

Safety switch activated

— Section where operation suspension was lifted upon completion of the measures.
 — Section where operation suspension was lifted upon completion of the measures.

Disaster prevention measures for earth structure sections at JR East

Disaster Prevention Information System

【PreDAS】 Prevention of Disaster Alarm System
(防止、予防策) (天災) (警報) (制度)



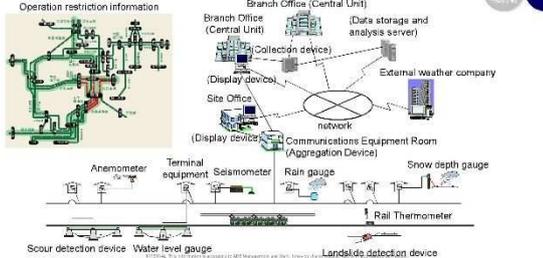
Main features

- 1) Connect observation equipment online and collect data automatically
- 2) Observation data can be grasped in real time (efficient operation restrictions)
- 3) The history of operation restrictions and data at the time of the disaster can be viewed

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Disaster prevention measures for earth structure sections at JR East

Disaster Prevention Information System

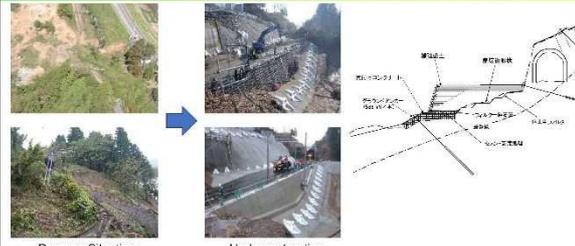


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Reference

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RRR Construction System implemented by JR East
Case of earthquake damage (Niigata-chuetsu Earthquake, 2004)



Damage Situation → **Under restoration**

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RRR Construction System implemented by JR East
Case of heavy rain damage (Niigata-Fukushima Heavy Rain, 2011)



Damage Situation → **completed state**

Operation resumed

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RRR Construction System implemented by JR East
Case of Yokohama Hazawa No.1



Under construction → **After construction**

Railway line was added by constructing earth structures on the limited site.

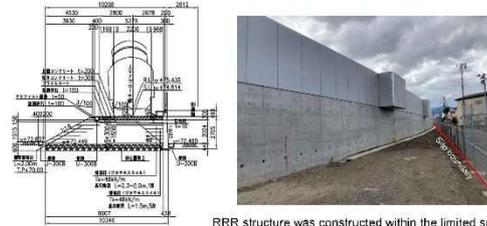
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RRR Construction System implemented by JR East
Case of YokohamaHazawa No.2



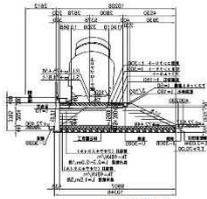
RRR structure in under construction

RRR Construction System implemented by JR East
Case of Fukushima approach No. 1



RRR structure was constructed within the limited space.

RRR Construction System implemented by JR East
Case of Fukushima approach No. 2



Inverted figure



On the other side. If there is enough space, earth structure with slope was constructed.

Thank you for your attention

II-3-6 G. Venkatappa Rao (Emeritus Prof. Indian Institutes of Technology)



TO ALL ESTEEMED EXPERTS, ENGINEERS AND DELEGATES
OF
JICA; NHRCL; ADBI; JARTS; RTRI; JRE; RRR-J; L&T; TCAP

JICA-NHRCL-ADBI-JARTS Knowledge Sharing Workshop on
Quality Control of Geosynthetic Reinforced Earth Structure and Disaster Prevention for High-Speed Rail



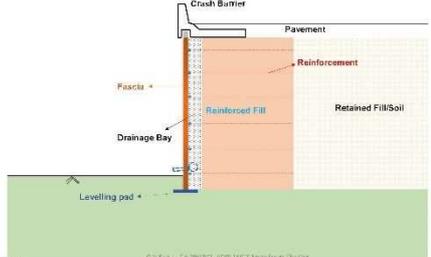
**Indian Experience with Geosynthetic Reinforced Earth Structures:
Key Considerations for Adapting Japan's RRR System**

Presented by
Dr. G. Venkatappa Rao
Indian Institute of Technology Gandhi Nagar
Geosynthetics Technology Advisory Services LLP Jaipur



24 OCT 2024

Components of Geosynthetic Reinforced Soil Wall – Indian Highways



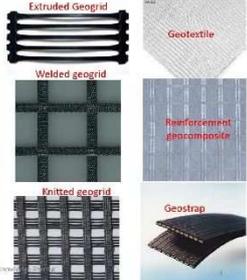
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Different Types of Reinforcement - Highways

- Function**
 - To stabilize the reinforced fill
 - To support the facing
- Properties**
 - Long-term tensile strength
 - Interaction with soil
 - Connection with facing
 - Easy installation

Commonly used reinforcements in India:

- Metallic strips of galvanised steel
- Metallic grids and meshes of galvanised steel
- Polymeric strips of polyester
- Geogrids of polyester and HDPE (presently uncommon)
- Geotextiles of polyester



24 OCT 2024

Reinforced Fill - Highways

- Earth pressure**

$$\sigma_h = K_a \gamma H$$

$$K_a = \frac{1 - \sin \phi}{1 + \sin \phi}$$
- Soil – reinforcement bond**
- Pore-pressures**
- Installation damage**
- Durability of reinforcement**

Property	IS 8006 (SHW 600)					IS: 18591 and FHWA		NCMA Morth	
	6I	6I	7B	7C	7D	100	20	75	
Max Grain size(mm)	125	125	-	125	125	100	20	75	
% Fines (< 63/75 μ)	<15	<15	-	15-45	15-45	≤15	≤35	<15	
% Clay (< 2 μ)	-	-	-	0-20	0-20	-	-	-	
Liquid limit	-	-	-	≤ 45	≤ 45	-	-	-	
Plasticity Index	-	-	-	≤ 25	≤ 25	≤ 6	≤ 20	≤ 6	
Coeff. of uniformity	> 10	5-10	-	-	-	≥ 4	-	-	
φ'	-	-	-	-	-	-	-	≥ 30°	

24 OCT 2024

Facing - Highways

- Protection to reinforced fill against **ravelling, erosion** etc.
- To prevent **local failures**
- To **protect the reinforcement** from external weathering
- Formwork to reinforced fill under compaction
- To have nice Aesthetics to wall
- Protection of the structure from external shocks and abrasions.

- Incremental concrete panel
- Block
- Wrap-around fascia
- Welded wire mesh
- Gabions
- Full-height concrete panel



Fascia role is not stabilizing reinforced soil mass in flexible-faced reinforced soil walls used in India

24 OCT 2024

General Design Considerations – Highways Flexible RS wall Systems

- Inward batter is provided to accommodate construction stage deformations.
- Post-construction and operational stage deformation restrictions are not stringent in highways.
- Generally, the creep of reinforcements is limited to 1%
- Post-construction settlements are limited to 100 mm in 10 years

24 OCT 2024

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7

Common Causes for Distress in GRS walls in Indian Practice

- Non-uniformity of fill type within the wall
- Low Compaction - quality control
- Poor Foundation - global stability/settlement issues
- Poor Construction and the presence of hydrostatic pressure.



8

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8

IS 3888-2014
Indian Standard

भूतलिक प्रवर्धित मृदा संरचनाएँ – कोडि प्रवर्धित

Geosynthetic Reinforced Soil Structures – Code of Practice

IS 3888-2014

भारतीय मानक

भूतलिक प्रवर्धित मृदा संरचनाएँ – कोडि प्रवर्धित

www.bis.org.in

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October 24, 2024

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RRR : Reinforced-soil Railway/Road Structures with a Rigid Facing

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Full Height Rigid Faced GRS Walls – RRR System

- Stage Construction – Wrap around is constructed first. After completion of construction stage deformations, cast-in-situ concrete fascia is constructed. (More advantage in soft foundations)
- Use Fascia Rigidity – High confinement at face
- Minimal Post construction Deformations – Operational Deformations
- Shorter length of reinforcements (0.4H) @ 0.3 spacing
- High quality compaction requirements
- Full compaction can be achieved even at face

- Fresh concrete touches reinforcement – full connection
- Requirement of High Alkaline Resistant Geosynthetic Reinforcement – PVA
- Roots with anchor pilots placed during 1st stage of construction
- It's inside get least into fresh concrete
- Its purpose is to support the formwork
- Spacing of 0.6m

- Gravel/sand bags provides confinement for wrap around during compaction
- Also provides face drainage
- Fresh concrete penetrates into it and bonds

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Fascia role is not stabilizing reinforced soil mass in present flexible-faced reinforced soil walls used in India

Now

In RRR system, Fascia role is important in stabilizing (providing confinement) to reinforced soil mass and helps in reducing post-construction and operational deformations

In the RRR system, the connection of geogrid to the fascia is very important which is achieved by fresh concrete touching the geogrid during fascia casting

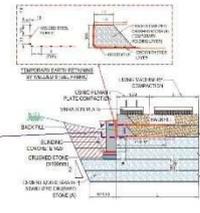
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RRR System – Construction – Method Statement – Indian HSR

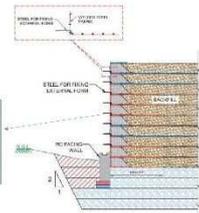
- Casting of fascia shall be after placement of geogrid at geogrid level
- Below geogrid level, fascia is to be cast before fill placement
- But from the geogrid level, fascia (even formwork, steel reinforcement cages) shall be cast only after the construction of geogrid reinforced soil



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RRR System – Construction – Method Statement

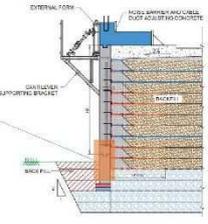
- How hooks are connected to welded steel fascia and steel reinforcement?
- Do these hooks have to carry any loads of formwork?



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RRR System – Construction – Method Statement

How should steel reinforcement of fascia be placed during the first stage of fascia construction? Does steel reinforcement extend the full height of the fascia?



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Few points – To Keep in Mind in RRR Construction in India

- Fill: Only relative compaction (density) is checked in QC in general. In India, it is important to check the gradation of fill at the site. Uniformity of fill material for the entire wall is important to avoid differential settlement issues.
- Slack of reinforcements should not happen.
- Surface drainage and drain at the toe shall be careful as it is near the tunnel entrance/exists...high water runoff is expected.
- Ground improvement design --- Is geotechnical data of the foundation of the site considered in design?



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A Few Clarifications Required in Method Statement

- What is the time period between the end of flexible fascia construction and concrete fascia casting?
- What is the detailing of geogrid reinforcement placement at the corner of the wall and abutment?
- Geogrid mentioned as bonded. Generally wovenknitted PVA? What is the manufacturing process of geogrids?
- Tests such as installation damage, alkaline resistance, creep, and dynamic tests need to be conducted if geogrids are manufactured in India. Concept of LONG TERM DESIGN STRENGTH.
- How the verticality of the wall maintained/ensured during flexible face wall construction?
- Full compaction can be done near the fascia in the RRR system. No need to worry about VIB deformations during flexible face wall construction?

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Japan International Cooperation Agency (JICA)
National High-Speed Rail Corporation Limited (NHSRCL)
Asian Development Bank Institute (ADBI)

Japan Railway Technical Service (JARTS)
High Speed Rail Innovation Center (HSRIC)

Dr. K. Seetharam
Dr. H.L. Suthar
Mr. Takano Koji
Mr. T. Kosaka

Dr. Kollu Mohan Krishna
Director, Geosynapse Private Limited, IIT Gandhinagar

Thank you



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II-4 Discussion with inquires and responses
II-4-1 Response to inquiry1

ANSWER to the question mentioned in the workshop

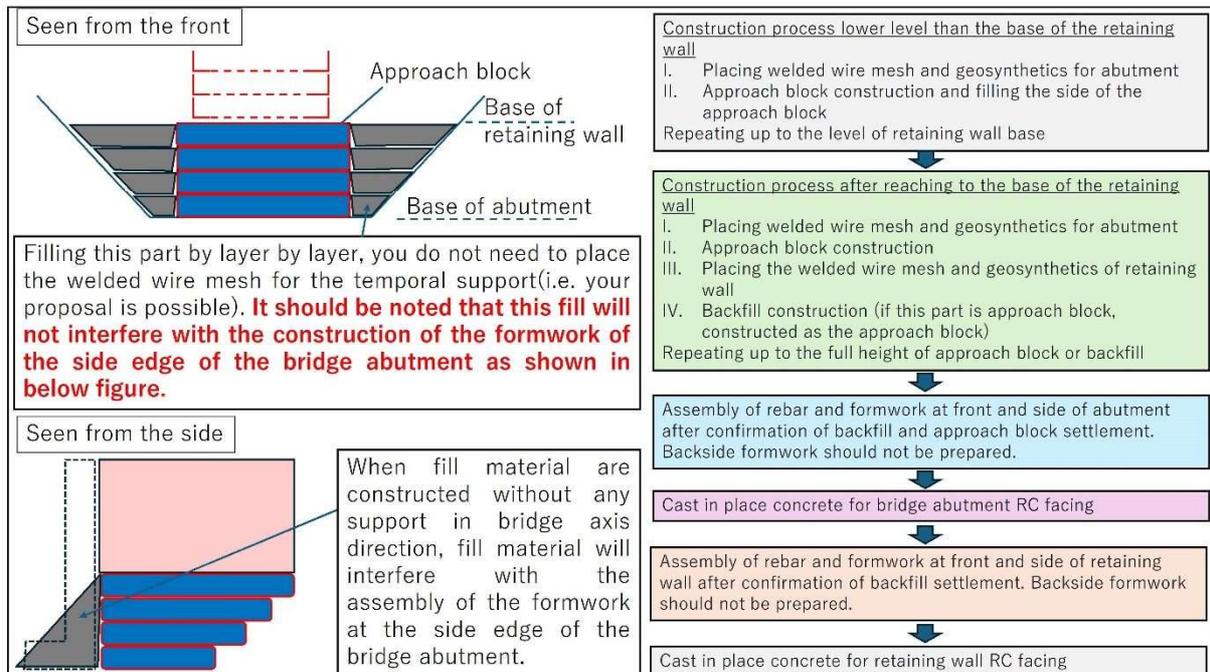
1. Adjusting the level of retaining wall base to the bridge abutment by excavation
2. Constructing approach block with installing the welded wire mesh and geosynthetics for the temporal support of side of approach block

Nakajima's answer in the workshop

3. Constructing approach block without installation of welded wire mesh and geosynthetics for the temporal support but filling the space between the edge of the approach block and ground at the side.

Proposal from L and T.

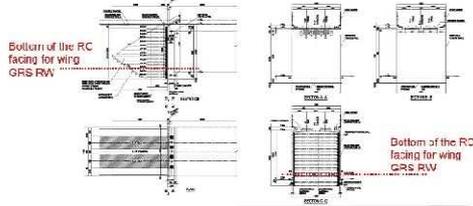
In next slide, comment to the proposal from L and T is summarized.



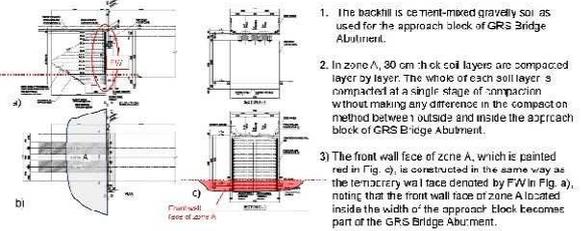
II-4-2 Response to inquiry2

In this PPT, the construction procedure of GRS BA and its wing GRS RWs is explained based on the approved drawing.

For this explanation, it is assumed that the bottom of RC facing for wing GRS RWs is located at a horizontal dotted line shown in this figure.



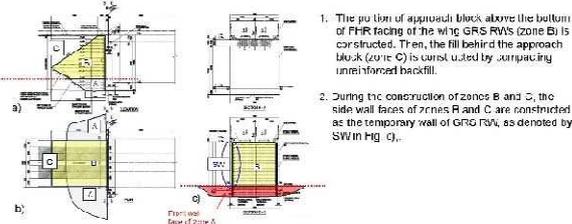
Step 1: Construction of the fill below the bottom of FHR facing for wing GRS RWs (zone A)



1. The backfill is cement-mixed gravelly soil as used for the approach block of GRS Bridge Abutment.
2. In zone A, 30 cm thick soil layers are compacted layer by layer. The whole of each soil layer is compacted at a single stage of compaction without making any difference in the compact on method between outside and inside the approach block of GRS Bridge Abutment.
3. The front wall face of zone A, which is painted red in Fig. c), is constructed in the same way as the temporary wall face denoted by FW in Fig. a), noting that the front wall face of zone A located inside the width of the approach block becomes part of the GRS Bridge Abutment.

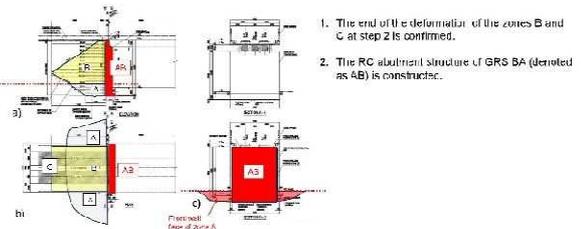
The size of zone A is arbitrarily determined.

Step 2: Construction of the portion of the approach block above the bottom of FHR facing for wing GRS RWs (zone B) followed by the construction of the unreinforced fill behind Approach Block (zone C).



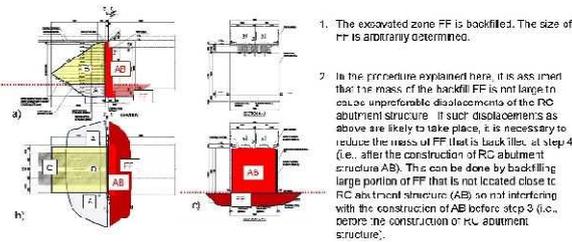
1. The portion of approach block above the bottom of FHR facing of the wing GRS RWs (zone B) is constructed. Then, the fill behind the approach block (zone C) is constructed by compacting unreinforced backfill.
2. During the construction of zones B and C, the side wall faces of zones B and C are constructed as the temporary wall of GRS RW, as denoted by SW in Fig. c).

Step 3: Construction of RC abutment structure of GRS BA after the end of deformation at step 2.



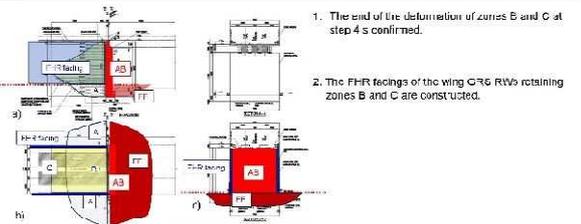
1. The end of the deformation of zones B and C at step 2 is confirmed.
2. The RC abutment structure of GRS BA (denoted as AB) is constructed.

Step 4: Filling of backfill in front of RC abutment structure of GRS BA



1. The excavated zone FF is backfilled. The size of FF is arbitrarily determined.
2. In the procedure explained here, it is assumed that the mass of the backfill FF is not large to cause unpreferable displacements of the RC abutment structure. If such displacements as above are likely to take place, it is necessary to reduce the mass of FF that is backfilled at step 4 (i.e., after the construction of RC abutment structure AB). This can be done by backfilling large portion of FF that is not located close to RC abutment structure (AB) so not interfering with the construction of AB before step 3 (i.e., before the construction of RC abutment structure).

Step 5: Construction of FHR facing for wing GRS RWs after having confirmed the end of deformation at step 4.



A Few clarifications required

- How the verticality of the wall maintained/ensured during flexible face wall construction?
- To maintain the verticality of flexible wall face, it is necessary to construct temporary walls with setbacks in advance accounting for the amount of deformation that is expected to take place by wall construction. It is required to perform a test construction to determine the amount of setback.
- The above background is shown on Page 9 of this PPT
- How should steel reinforcement of fascia be placed during the first stage of fascia construction? Does steel reinforcement extend the full height of the fascia?
- As shown on Page 3 of this PPT, the steel reinforcement members for the fascia is assembled from the foundation of the fascia that has been constructed before the start of the construction of the geosynthetic-reinforced backfill. However, casting-in-place of fresh concrete to construct the fascia is after the end of the deformation of the backfill and subsoil caused by the construction of geosynthetic-reinforced backfill.
- Full compaction can be done near the fascia in the RRR system. No need to worry about deformations during flexible face wall construction?
- Compaction near temporary wall should be done by hand operated-tamping allowing bulging at the wall face as shown on Page 9 of this PPT, not by heavy machinery to avoid its falling down. Experiences indicate that even hand operated-tamping as shown on Page 10 of this PPT can satisfy the compaction control specifications.
- As mentioned above, the deformation problem can be alleviated by constructing a temporary wall surface with a setback of about 1 to 2 cm in advance for every temporary facing unit.

e) Compaction of Crusher Run and Backfill (continued)

When constructing a GRS retaining wall or a GRS abutment, each temporary facing units should be arranged with a proper setback (typically about 1 - 2 cm) relatively to the unit immediately below so that the alignment of the temporary wall face at the end of the construction to the full wall height is maintained vertical enough.

[Background]

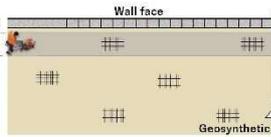
This setback is to ensure the thickness of "the full-height RC facing constructed by casting-in-place the fresh concrete over the temporary facing units" indicated in the drawing. The arrangements of temporary facing units without a proper set back results in an inclination from the vertical of the temporary wall face that becomes larger at higher wall levels. Then, the concrete facing becomes thinner than the one specified in TS with this trend becoming stronger at higher levels of the wall.

To evaluate the amount of proper setback, the following on-site method is known to be effective. During a trial construction of GRS retaining wall (and/or a GRS bridge abutment), the ultimate cumulative lateral external displacement Δ at the front vertical face of a given temporary facing unit that would take place by the construction of the current soil layer and subsequent overlying soil layers is evaluated. To this end, at a couple of temporary facing units, the horizontal movement at the target arranged on the vertical front face of the temporary facing unit is measured before the start of the construction of the current soil layer and also at the end of the construction of each of the subsequent overlying five soil layers.

Appropriate compaction of the backfill

Hand-operated tamping

About 1.0m



Compaction of backfill soil by hand-operated tamping

- Compaction within about 1.0 m next to the wall face by hand-operated tamping .

Six key construction steps for RRR-GRS retaining walls (3/6)



The water content of the backfill is not lower by 3 % and not higher by 1 % than the optimum water content evaluated by using compaction energy of **Modified Proctor**.

The dry density of compacted soil is at least 95 % of the maximum dry density by **Modified Proctor**.

Photo courtesy : TAISEI Co., Ltd

II-4-4 Response to inquiry4

Prospective Questions for Interaction Session

In today's session, we had a very engaging discussion on one of the most crucial topics of megaproject construction—i.e., construction of geosynthetic reinforced soil structures essentially from the perspective of disaster preparedness.

Based on our expert presentations, I would like to open the floor with a few questions for our panelists and all the participants:

1. To Nakajima Sensei or Tamai Sensei- You talked about several aspects related to the construction of GRS Structures, particularly material quality and construction techniques. However, my question is, **what is the most challenging step (in terms of logistical issues, procurement, etc.) in your experience while constructing GRS Structures for High-Speed Rail?** If you could elaborate with examples.
2. **To Kosaka San (construction of wall abutments) - What potential risks are associated with the structure, and how will they be mitigated? Are there any risk factors related to geosynthetic degradation, soil stability, or unforeseen environmental changes?**

[Response to No. 2]

With the GRS Retaining Wall and GRS Bridge Abutments for India High Speed Rail, one of the most serious risks is long-term and sudden uneven settlement at the RC slab track constructed on them. This will endanger the safe operation of High Speed Rail. The long-term settlement may take place by the selfweight of the backfill and train loads. Sudden settlement may take place by earthquakes, heavy rain and flood. However, safe operation of Shinkansen constructed on many RRR GRS structures for last more than 30 years in Japan has proven that this risk is mitigated by their proper construction in the following terms.

- 1) The use of proper geosynthetic reinforcement (i.e., geogrid) having high alkaline resistance because of direct contact with fresh concrete; high pull-out resistance in the backfill and concrete; and a high rupture strength.
- 2) For the construction of geosynthetic-reinforced backfill, the use of proper temporary facing units of welded steel wire mesh. The temporary units should be flexible enough to accommodate the deformation of the backfill and subsoil caused by the construction of the backfill, while should be stable enough against the earth pressure and compaction forces during backfill construction.
- 3) The use of backfill of high quality; and good compaction and its confirmation. For the approach block of GRS Bridge Abutment, uniform mixing of backfill with cement at the optimum water content.
- 4) Confirmation of sufficient settlement of the backfill caused by its construction before the start of the construction of RC facing for GRS Retaining Wall and RC abutment structures for GRS Bridge Abutment. The RC facing and RC abutment structure should be constructed by casting-in-place fresh concrete in such that they are firmly connected to all the geosynthetic-reinforcement layers.

These five terms are all unique essential requirements for RRR GRS structures.

The risk by unforeseen environmental changes includes the followings:

- 1) Strong shaking of GRS structures by severe earthquakes: In this respect, a high seismic stability of RRR GRS structures has been proven by their satisfactory performance, as expected, during a couple of past major earthquakes in Japan.

- 2) Erosion and scouring in the subsoil supporting GRS structures by flood. In this respect, the performance of RRR GRS structures against flood and ocean wave attacking them was satisfactory in past several events. This is due largely to the use of full-height rigid facing well integrated to the geosynthetic-reinforced backfill.
- 3) Fire attacking the GRS structures. The damage can be effectively mitigated by the use of full-height rigid facing.
- 4) Settlement of GRS structure by compression of soft soil layer due to drawdown of ground water level after the start of service. This problem is difficult to avoid if it takes place. It should be confirmed at the stage of planning that this type of problem will not take place at the site of planned GRS structure. On the other hand, after the settlement of the backfill due to the subsoil compression, the full-height rigid facing is constructed then RC slab tracks are arranged. So, the residual settlement of RC slab tracks by the compression of subsoil after the start of service is minimized.

3. To JR East, Takisawa San: (one of the most important topics related to safety from disasters). As you may know, India is now facing several sudden natural disasters, particularly floods due to climate change.

We visited the field yesterday. Based on your observation and as an expert in running Japanese HSR, what should be the five most important (he already mentioned several points in his presentation) points that Indian engineers should keep in mind to mitigate damage in times of natural disaster?

4. To Koshiishi San (maintenance of earth structures): Long-term stability and serviceability. How long is the structure expected to perform without requiring significant maintenance or repair? What are the predicted degradation rates of geosynthetics and soil?
5. To Prof Rao—You are a pioneer in India in geosynthetic structures and know the Indian scenario well, particularly in highway construction. What practical examples/experiences from highways can be crucial for HSR engineers to learn from?
6. General Question on Maintenance and Monitoring: What level of maintenance will be required over time, and how will the structure be monitored for performance? (this question can be asked to Prof Rao as well, quoting his experience from highways)
7. General Question on Vegetation or erosion control: Does vegetation have a role in stabilizing the slope or embankment? How will geosynthetics support or interact with vegetation regarding growth and root penetration?

[Response to No. 7] With RRR GRS Retaining Wall and GRS Bridge Abutment, the vegetation has no role in stabilizing the structure. The interaction of geosynthetic and vegetation regarding growth and root penetration is generally not an issue, as the wall face is fully covered with RC facing, like the conventional RC retaining walls.

8. General Question on Long-term cost-effectiveness: From the Japanese experience, what share of the overall cost is of geosynthetic materials, soil, and construction labor compared to other traditional methods (e.g., concrete retaining walls)?
9. Long-term cost-effectiveness: How do the initial construction costs compare to the long-term maintenance and operational costs?

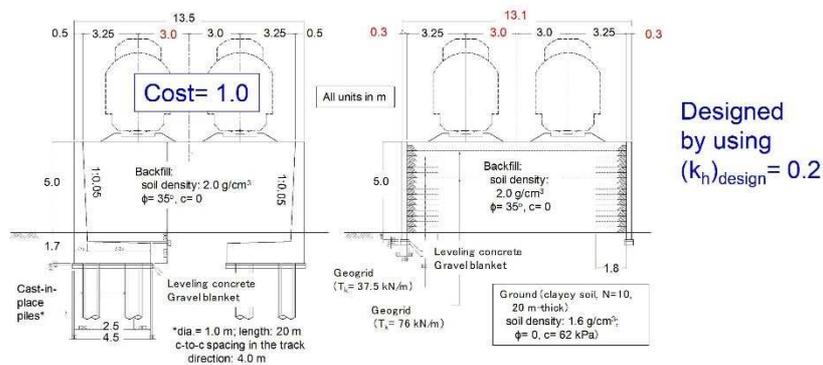
[Response to Nos. 8 & 9] The following is the cost comparison between a typical embankment for two tracks supported by a pair of RRR GRS retaining wall and the

one by a pair of conventional RC cantilever retaining walls. A large cost reduction with RRR GRS retaining walls result from:

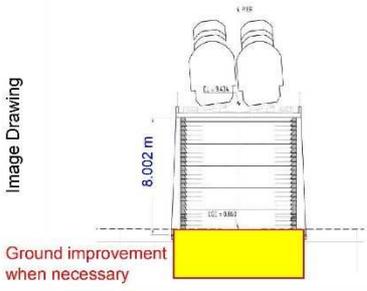
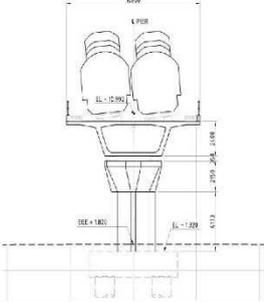
- 1) a less amount of concrete and steel reinforcement;
- 2) no cost for a pile foundation when the conventional RC retaining wall needs a pile foundation (as in the ordinary case); and
- 3) low maintenance cost with RRR GRS retaining walls because of small residual settlement; a very high wall stability; and a very high durability of wall face.

Cost Ratio: GRS RW versus conventional type RW

	Construction	Maintenance	Total
20 m-thick relatively soft ground: - piles for conventional type RW s - no piles for GRS RW s (the case shown in the figure)	0.32	0.5	0.33
Relatively stiff ground: - no piles for conventional type RW s & GRS RW s	0.81	0.51	0.77



In addition, as shown in the example shown below, the construction cost for an embankment retained by a pair of RRR GRS RW is substantially lower than the one for conventional RC viaduct, because pile foundations are usually essential with RC viaduct, whereas it is not with RRR GRS RW. The construction cost with RRR GRS RW reduces with a decrease in the depth of ground treatment.

		RRR GRS RW	RC viaduct (pier + beam)									
Image Drawing												
	Approximated cost	<table border="1"> <thead> <tr> <th>Depth of Ground Treatment</th> <th>Approximated cost</th> </tr> </thead> <tbody> <tr> <td>d=0.0m</td> <td>1 million JPY/m (0.50)</td> </tr> <tr> <td>d=5.0m</td> <td>1.35 million JPY/m (0.68)</td> </tr> <tr> <td>d=7.5m</td> <td>1.5 million JPY/m (0.75)</td> </tr> <tr> <td>d=10.0m</td> <td>1.7 million JPY/m (0.85)</td> </tr> </tbody> </table>	Depth of Ground Treatment	Approximated cost	d=0.0m	1 million JPY/m (0.50)	d=5.0m	1.35 million JPY/m (0.68)	d=7.5m	1.5 million JPY/m (0.75)	d=10.0m	1.7 million JPY/m (0.85)
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d=7.5m	1.5 million JPY/m (0.75)											
d=10.0m	1.7 million JPY/m (0.85)											

*Approximate cost is calculated by the unit price and artificial in Philippines.

Source: JICA Study Team

**III. Fourth workshop [19-22 May 2025]
(In Japan with visiting GRS structures
at Oshamanbe for Hokkaido Shinkansen)**

III-1 Workshop agenda including the list of participants



ADBI-JICA-NHSRCL-JARTS KNOWLEDGE SHARING WORKSHOP

<topic>

Date: 22 May 2025

Time: 14:00 – 18:00 Japan Time

Venue: ADBI Office (Hybrid event for Session 3)

<zoom link to be provided>

Organizing Partners:

Japan International Cooperation Agency (JICA)
 National High-Speed Rail Corporation Limited (NHSRCL) Asian Development Bank
 Institute (ADBI)
 Japan Railway Technical Service (JARTS)

Supporting Partners:

High Speed Rail Innovation Center (HSRIC)

18 May 2025	
	Travel to Japan from India
19 May 2025	
Time (JST)	Agenda
13:00-13:15	Visit Railway Technical Research Institute (RTRI) Greeting with RTRI executive
13:15-16:00	Visit to test facilities, GRS retaining wall and GRS Integral Bridge abutment in RTRI
16:15-18:00	Workshop
20 May 2025	
	Travel from Tokyo to Shin Hakodate and stay one night
21 May 2025	
	Technical Site Visit at Oshamambe, Hokkaido Site 1:GRS wall construction site of ramp to maintenance base Site 2:GRS wall construction site of Hokkaido Shinkansen Site 3:GRS wall construction site of maintenance base Site 4:GRS bridge abutment construction site of Hokkaido Shinkansen Site 5 GRS integral bridge abutment construction site of Hokkaido Shinkansen
	Move to Sapporo and stay one night in Sapporo
22 May 2025	
11:30	Travel back to Tokyo
14:00 – 18:00	Workshop at ADBI

AGENDA OF WORKSHOP at RTRI (The topic may be changed)

Topic 1: Confirmation of important matters regarding the construction of reinforced soil structures.



Topic 2: Explanation about Construction procedure of GRS Bridge Abutment and wing GRS RWs having RC abutment structure and RC facing with different bottom levels
 Topic 3: Questions from Indian engineers for the design and construction of GRS wall and GRS bridge abutment

AGENDA OF WORKSHOP at ADBI

Time (JST)	Duration	Agenda
13:45 – 14:00	15mins	Housekeeping Rules
14:00 – 14:15	15mins	Opening Remarks ADBI JICA RTRI Embassy of India
14:15 – 15:45	90mins	Session 1: Key Learnings from the Field Trip with Participants (Part 1) Introduction of the Chair and Session Speakers Moderator: Nikhil Bugalia, Assistant Professor, Indian Institute of Technology Madras <i>Tentative presenters: NHSRCL, TCAP, contractors/engineers</i> Expert Presentation 1: (15 minutes) <Name of Presenter> <Name of Affiliation> Expert Presentation 2: <topic> (15 minutes) <Name of Presenter> <Name of Affiliation> Expert Presentation 3: <topic> (15 minutes) <Name of Presenter> <Name of Affiliation> Q&A Session (45 minutes)
15:45 – 16:00	15mins	Coffee Break
16:00 – 16:30	30 mins	Session 2: Key Learnings from the Field Trip with Participants (Part 2) Q&A Session (30 minutes) (Cont'd)
16:30 – 17:30	60mins	Session 3: Wrap-up session on Long-term Contribution from Japan for training Indian HSR Staff Moderator: Hironori Kato, Professor, The University of Tokyo (TBC)



17:30 – 17:45	15mins	<p><i>Tentative presenters: Engineers tutor, civil engineers to share (e.g rolling stocks) from JARTS, JREast, RR with engineer field</i></p> <p>Expert Presentation 1: (TBC) (15 minutes) <Name of Presenter> <Name of Affiliation></p> <p>Expert Presentation 2: <topic> (15 minutes) <Name of Presenter> <Name of Affiliation></p> <p>Q&A Session (30 minutes)</p> <p>Closing Remarks</p>
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Itinerary for Site Visit of RRR Workshop Construction site

as of 7 May 2025

Date	18th May, Sun	19th May, Mon	20th May, Tue	21st May, Wed	22nd May, Thu	23rd May, Fri	
	Time	Event	Time	Event	Time	Event	
AM	7:55 Arrival at Haneda Airport (AI 358)	7:30 Meet at Lobby (distribution of tickets) 7:50 Leave Hotel for Tokyo St. 8:00 Meet at Tokyo Station 8:18 Departure by Tohoku Shinkansen 11:15 Meet at lobby (guided by ATRI Staff) 11:25 Leave Hotel 11:30 Take JR Chuo line 12:30 Arrive RTRI visit Shinkansen museum 13:00 Workshop for RRR 13:15 visit to test facilities 15:30 Coffee Break 16:00 Workshop 17:30 End of Workshop 17:30 Leave RTRI	7:30 Hotel Check out by 7:30 8:00 Meet at Lobby (distribution of tickets) 8:00 Leave Hotel for Tokyo St. 8:18 Meet at Tokyo Station Departure by Tohoku Shinkansen 10:20 Havahusa 5 12:15 Shin-Hakodate Hokuto St. 12:25 from South Exit to Bus Parking area by bus 13:00 Arrive at Parking at Goryokaku (Free time) Lunch available at Indian 15:00 Meet at Bus 15:30 Arr. Mount Hakodate (Free time for 45 min) Dept. 16:15 16:30 Arr. Kanemori Warehouse (Free time for 60 min) Dept. 17:30 17:45 Arr. Hotel and Check In	8:00 Hotel Check out by 7:50 Leave hotel Bus will be in front of the By bus (Approx. 1H40M-2H) 10:00 1. Entrance of Toyono Tunnel 10:20 By bus 11:10 2. 2nd and 3rd Shizukari embankment section 12:00 Checking for the place to purchase lunch box (TBC)	7:30 Hotel Check Out by 7:30 7:45 Leave Hotel 8:02 Saanoro Station ↓ 8:37 Shin Chitose Airport St. 9:30 Departure from Shin-Chitose (ANA 54) ↓ 11:10 Arrive at Haneda Airport 12:00 by bus to ADBI 12:30 Lunch at ADBI 14:00 Wrap Up Meeting at ADBI, Tokyo 18:00 End of Workshop 18:30 Arrive at Hotel Hotel Check In	11:50 Departure from Haneda Airport (AI 357)	
Lunch							
PM	15:00 Hotel Check In						
Dinner	Free	Free	Free	Free	Free	Free	
Stay	JR-EAST Hotel Mets Premier Akihabara 1-17-4 Soto-Handa, Chiyoda-ku, Tokyo 101-0021 Tel. 81-3-5294-1011 https://www.hotelmets.jp/en/akihabara/	JR-EAST Hotel Mets Premier Akihabara 1-17-4 Soto-Handa, Chiyoda-ku, Tokyo 101-0021 Tel. 81-3-5294-1011 https://www.hotelmets.jp/en/akihabara/	ROUTE-INN GRANTIA HAKODATE EKIMAE 21-3 Wakamatsu-cho, Hakodate, Hokkaido 040-0063 https://www.route-inn.co.jp/hakodate-st/ 地図：インディアンレストラソ SUSUMU HAKODATE- 五輪場公団前/インズカレ [R-517] (tabelog.com)	JR-EAST Hotel Mets Premier Sapporo 5-3 Nishi 2, Kita 7, Kita-ku, Sapporo, Hokkaido 060-0807 Tel. 81-11-729-0011 https://www.hotelmets.jp/saanoro/facility-as.html	Villa Fontaine Shiodome 1-9-2 Higashi-shimbashi, Minato City, Tokyo, 105-0021 Tel. 81-3-3569-2220 https://www.vf.jp/en/s/shiodome/		
Restaurant Information							

INTERNAL: This information is available to ADB Management and Staff. It may be shared outside ADB with appropriate permission.

List of participants

NO.	Name	Organization	Position	Remark
1	Mr. H L Suthar	NHSRCL/HSRIC	PED/T&D & DG, HSRIC	
2	Sri Satish Chourasia	NHSRCL	CPM/Vasai	
3	Sri Seemanchal Padi	NHSRCL	JGM/Mumbai	
4	Sri G V Dahake	NHSRCL	DGM/Civil	
5	Sri Vipin Kumar Bansal	NHSRCL	SrMgr Design	
6	Dr. Amit Prashant	IIT-Gandhinagar	Professor	
7	Dr. Kolli Mohan Krishna	IIT-Gandhinagar	Research Associate	
8	Prof. Murali Krishnan	IIT-Tirupati	Professor	
9	Mr. Pranav Kumar	DRA, D-1 Package	VP Technical	
10	Mr. Keshav Rao	TCAP (PMC-Civil)	Chief Geotechnical Engineer	
11	Mr. Sanjay Bhargava	TCAP (PMC-Civil)	Chief Resident Engineer	
12	Mr. Satish Naik	BGPL (Best-Geotech),	Director	
13	Ms. Annaluru Usha	L&T	DGM	
14	Mr. Rajkumar K	L&T	JGM	
15	Mr. Akhilesh Kumar Singh	L&T	Sr Const Mgr	
16	Dr. Nikhil Bugalia	ADBI	Assistant Professor, IIT Madras	
17	Dr. Susumu Nakajima	RTRI	General Manager	
18	Mr. Takumi Ozaki	RTRI	Researcher	
19	Mr. Shinji Morimoto	JICA	Chief Researcher	
20	Mr. Koji Takano	JRE	Deputy Director	
21	Ms. Ryoko Nakano	JRE	Deputy Director	
22	Mr. Takuya Kosaka	RRR-I Association	Chief secretariat	
23	Dr. Fumio Tatsuoka	RRR-I Association	Professor emeritus(Univ. of Tokyo and Univ. of Tokyo Science Univ.)	
24	Mr. Yukihiko Tamura	RRR-I Association	President	
25	Dr. Antoine Duttine	RRR-I Association		
26	Mr. Noriaki Ebii	RRR-I Association(YEBISUS)		
27	Ms. Noriko Kawashima	RRR-I Association(kuraray)		
28	Dr. Kenji Watanabe	The University of Tokyo	Professor	
29	Mr. Hajime Yoshida	JIC		
30	Mr. Noriyuki Kurihara	JIC		
31	Mr. VU NHAT LINH	JIC		

III-2 Pictures at Oshamanbe construction site and workshop







III-3 PPT presentations

III-3-1 Fumio Tatsuoka (Professor Emeritus, University of Tokyo, Tokyo University of Science)

19 May 2025
Visiting full-scale test embankments at RTRI

TATSUOKA, Fumio
on the behalf of RTRI & RRR International

A number of lessons were learned by the construction, long-term behaviour and loading tests of five full-scale test embankments having GRS retaining walls and GRS integral bridges. They were essential for the development of the RRR GRS structures.

The first three were constructed at University of Tokyo (1982, 1984 & 1986), followed by the last two at RTRI (1987 – 1988).

Two major lessons:

1) The facing of the five full-scale models was consecutively improved by learning that the wall deformation becomes very small and the GRS structures become very stable by using **full-height rigid (FHR) facing** connected to densely arranged geogrid layers.

2) The residual displacement of FHR facing becomes essentially zero by construction after the deformation of full-height backfill constructed using a temporary facing unit has taken place (**staged-construction**).

Chiba No. 1 embankment of clay backfill

- To examine whether stable reinforced clay walls can be constructed
- Constructed in 1982 at University of Tokyo
- A non-woven geotextile (spun-bonded 100 % polypropylene) usually used as a drain material but not as reinforcement due to very low tensile stiffness.
- Flat wrapped-around wall face.

Wrapped-around facing exhibited large deformation already during construction and more by rainfalls after construction and was not durable and vulnerable to UV light..... so cannot be used for important permanent walls.

Oct. 1985 Initial (June 1982)

Chiba No. 2 embankment of clay backfill

- To examine the effects of soil bags arranged at the wall face on the wall stability
- Constructed in 1984 at University of Tokyo
- Slightly larger than Chiba No. 1
- Clay backfill and non-woven geotextile as Chiba No. 1.

By using soil bags:

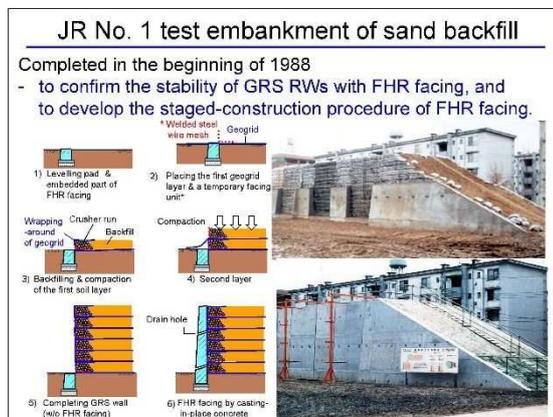
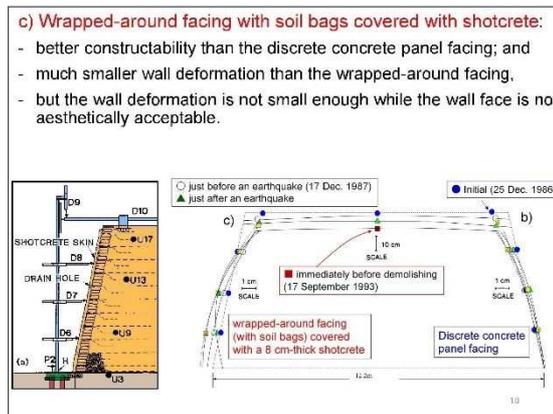
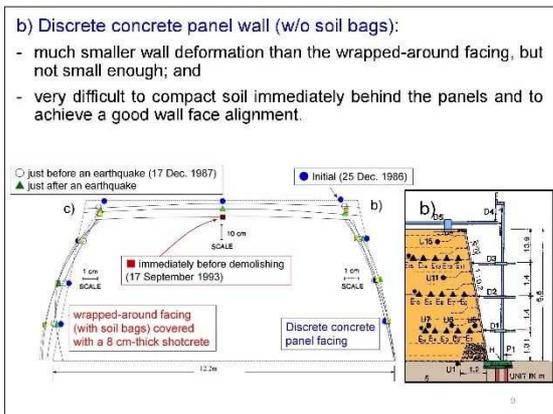
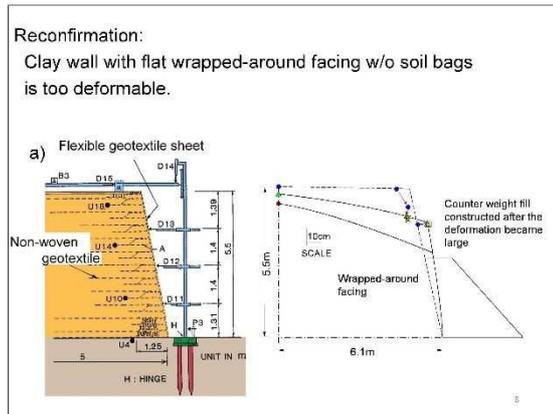
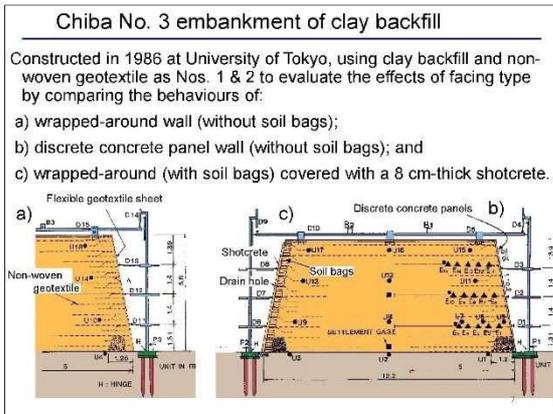
- good compaction; and
- good confinement,

thus high strength & stiffness of the backfill, resulting in:

a) very small long-term deformation;

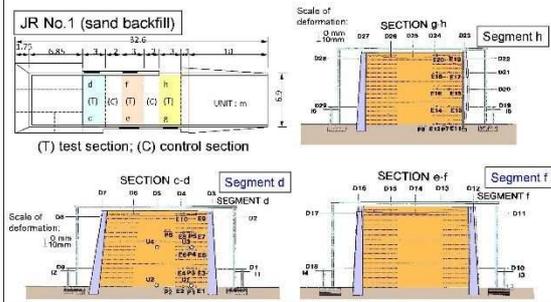
and

b) very stable behaviour in a heavy rainfall test supplying 70 m³ of water for 8 days from the crest.



Behaviour for two years after completion of two types of facing using gravel bags connected to geogrid layers:

- a) segment h: discrete panel facing → relatively large deformation
- b) the other segments: FHR facing → very small deformation



JR No. 2 embankment of clay backfill

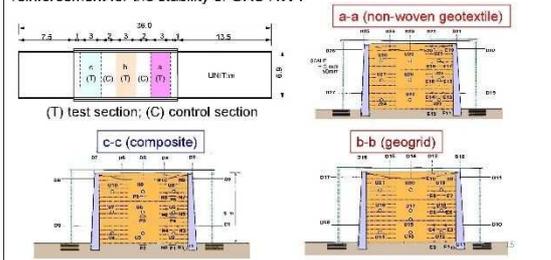
Constructed in the beginning of 1988 to examine the feasibility of GRS RW with FHR facing using clay



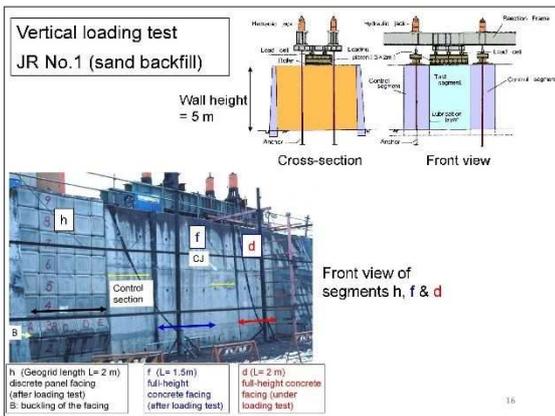
Volcanic ash clay (Kanto loam):
 $w_p = 120-130\%$; $S_u = 90\%$; &
 $\rho_d = 0.55-0.60 \text{ g/cm}^3$

- a-a: a non-woven geotextile (most extensible), as Chiba Nos. 1 - 3;
- b-b: a geogrid sandwiched between two gravel layers (most stiff); and
- c-c: a composite of non-woven/woven geotextiles (intermediate).

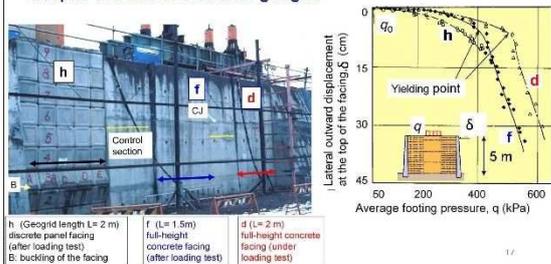
All three sections exhibited very good long-term performance, reconfirming that "the facing type could be more important than the stiffness of reinforcement for the stability of GRS RW".



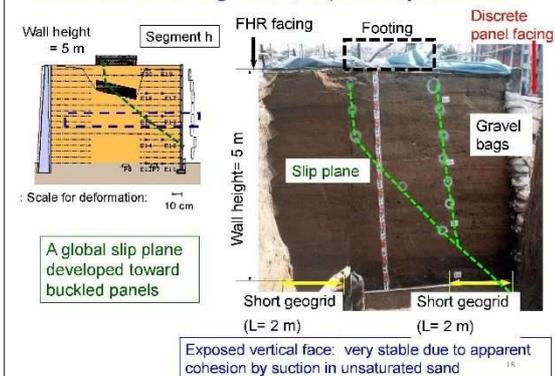
Vertical loading test JR No. 1 (sand backfill)

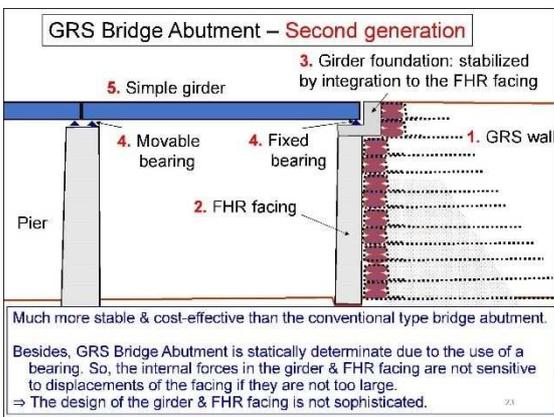
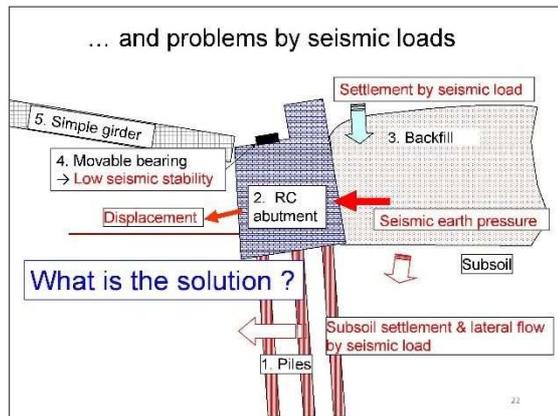
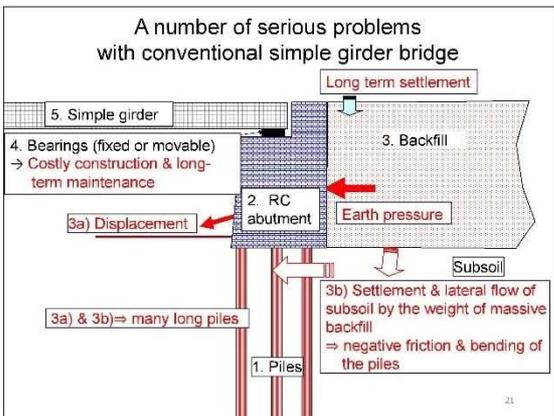
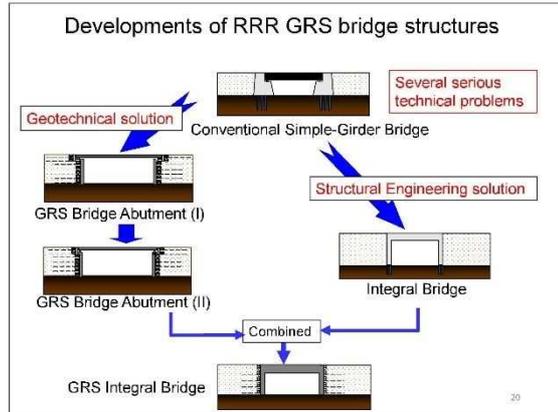
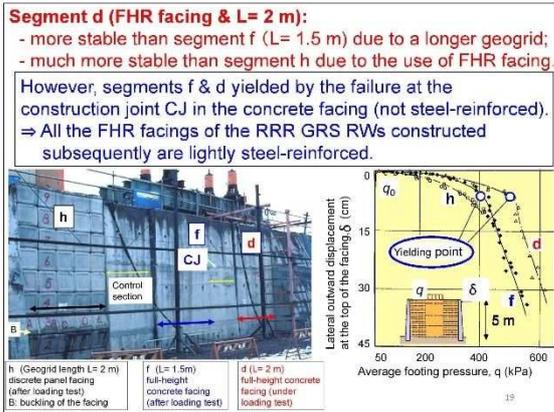


- Segment h (discrete panel facing & geogrid length L = 2 m) - the facing buckled, which resulted in the lowest wall stability
- Segment f (FHR facing & L = 1.5 m for a wall height of 5 m); - more stable than segment h due to the use of FHR facing, despite the use of a shorter geogrid



Cross-section of segment h, exposed by excavation





**GRS Bridge Abutment, completed 2020
Shimo-shinjo No. 1, Hokuriku Shinkansen**

By the courtesy of JRJT



GRS Bridge Abutment

Summary of GRS Bridge Abutment – Second generation

First GRS Bridge Abutment, at Takada for Kyushu Shinkansen

GRS Bridge Abutment at Mantaro for Hokkaido Shinkansen



- First one at Takada in 2003
- As of 2024, in total 185, including:
 - 41 for Hokkaido High Speed Railway (Shinkansen);
 - 79 for Kyushu HSR; and
 - 49 for Hokuriku HSR

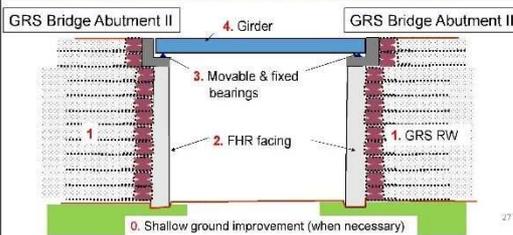
26

A pair of GRS Bridge Abutments (2nd generation) supporting both ends of a simple girder via bearings arranged at the crest of FHR facings

Two unsolved problems:

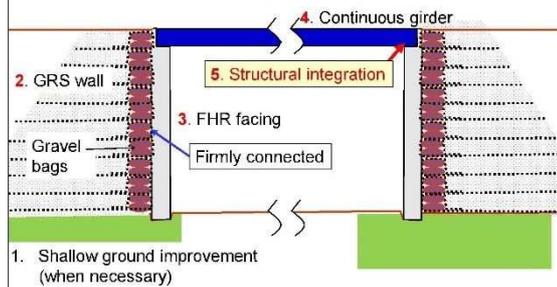
- 1) high cost for construction & maintenance of the bearings; and
- 2) low seismic stability of the girder at the movable bearing.

⇒ GRS Integral Bridge, alleviating these two problems.



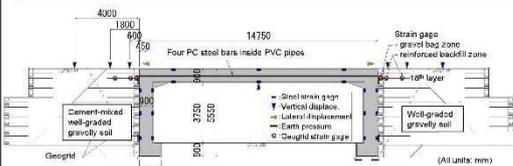
27

GRS Integral Bridge



28

Full-scale model of GRS Integral Bridge, completed Feb. 2009 at Railway Technical Research Institute, Japan



27 November 2008

April 2009

Loading method, 2012

Lateral cyclic loading tests simulating seismic & thermal effects

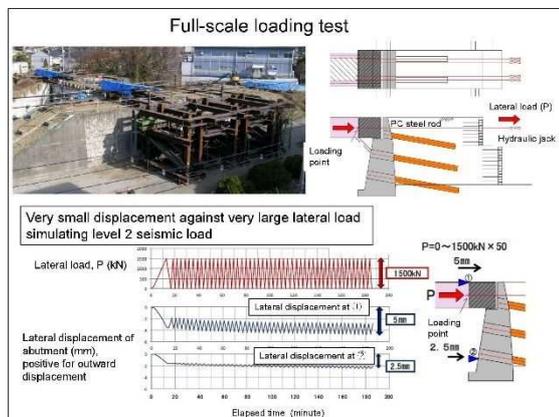
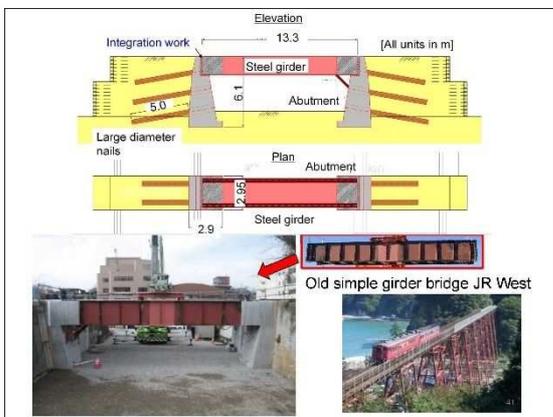
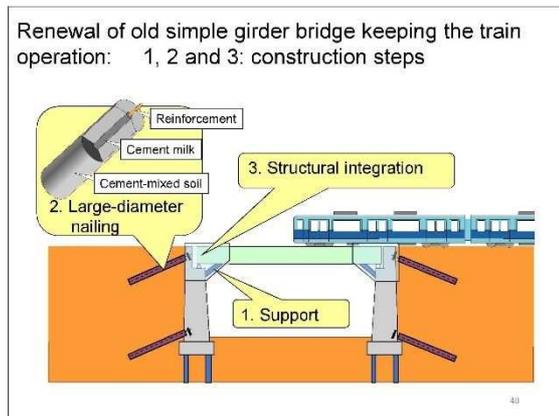
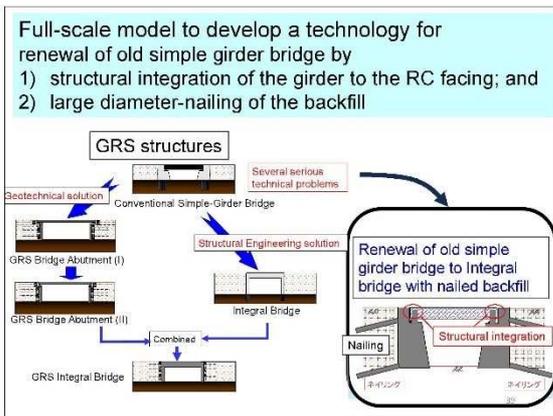


Hydraulic jacks

Reaction frame

Reaction frame

33



FUNDAMENTALS OF RRR GRS STRUCTURES

TATSUOKA Fumio
RRR International

- 1) Three major advantageous features
- 2) Fundamental structural mechanism
- 3) Three basic characteristic technologies
- 4) Five core construction procedures

1) Three major advantageous features of RRR GRS structures

Different from conventional type retaining walls and bridge abutments.....

- (1) **No pile foundation**, yet the FHR facing can support a mast for electric supply, wind/noise barriers, crash barriers, bridge girders and so on in a very stable and cost-effective manner.
- (2) **A very high stability of facing**, against long-term traffic loads applied very close to the wall face, severe seismic loads, floods and so on.
- (3) **Very small residual deformation**, so, no bump immediately behind the facing, resulting in very low maintenance cost. For High Speed Railway, the construction of continuous RC slab tracks on RRR GRS structures is the standard practice in Japan, and for HSRs in India

Continuous RC slab track 1/2

- Relatively high initial construction cost
- But, a very large reduction of maintenance cost
- **Very small allowable total settlement by the compression of the backfill and the subsoil:**
 - 30 mm/10 years (for required serviceability)
 - Less than 15 cm (for required restorability after a severe E.Q.)

Requirements for HSR in Japan

By the courtesy of Japan Railway Construction, Transport and Technology Agency

Continuous RC slab track 2/2

- 1) Not allowed to construct on ordinary embankments & the backfill retained by conventional type RWs, because small-enough settlement cannot be ensured.
- 2) Constructed on the reinforced backfill of RRR GRS structure is the standard practice, made possible by ensuring small compression of the backfill with high stability by:
 - a) the use of high-quality backfill and its good compaction; in addition to
 - b) closely-spaced geogrid layers with a vertical spacing of 30 cm that are firmly connected to FHR facing

By the courtesy of Japan Railway Construction, Transport and Technology Agency

2) Fundamental structural mechanism of RRR GRS structures, in comparison with conventional retaining walls

Conventional retaining walls

- (1) The facing is a cantilever structure that resists the large earth pressure of unbound backfill.
- (2) The facing is constructed before the construction of the backfill, so the facing displaces and deforms by the earth pressure.

⇒ Large forces in the facing, requiring massive & strong facing

⇒ Large overturning moment & large lateral thrust at the facing base, resulting in:

- unstable behaviour, particularly by severe seismic loads; and
- large stress concentration at the facing base.

So, usually a pile foundation is necessary.

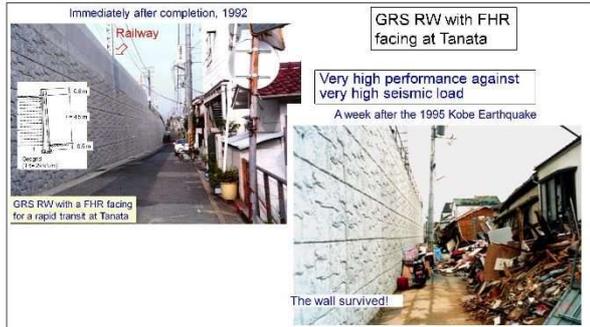
Collapse of gravity wall (i.e., cantilever RW) Ishiyagawa, 1995 Kobe Earthquake

Very dense gravelly subsoil, no pile

Overturning failure, despite seismic design using $k_h = 0.2$ with $(F_h)_{allowable} = 1.5$.
 ⇒ The conventional seismic design is not sufficient.
 ⇒ More stable wall type is required e.g., GRS RW with FHR facing

RRR GRS retaining walls and RRR GRS bridge abutments

- (1) The backfill is stabilized by dense geogrid-reinforcing.
- (2) FHR facing is constructed after the deformation of the backfill and the subsoil by the construction of the backfill has taken place (the staged-construction). Then, the FHR facing does not deform nor displace by the earth pressure from the backfill.
- (3) The FHR facing is "a continuous beam supported by many reinforcement layers at a small span (i.e., 30 cm)".



3D effects of full-height rigid (FHR) facing!

Each unit of "FHR facing firmly connected to the densely reinforced backfill" located between construction joints behaves as a monolith

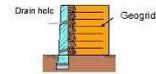
→ Even if local failure is going to take place somewhere in the wall, it does not develop towards the collapse of the whole wall.



3) Three basic characteristic technologies of RRR GRS structures

To ensure the advantageous features of RRR GRS structures

- (1) Full-height rigid (FHR) facing firmly connected to the densely arranged geogrid layers in a small vertical spacing (i.e., 30 cm) to enhance high performance as a composite.

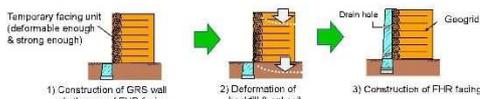


2) Three basic characteristic technologies of RRR GRS structures

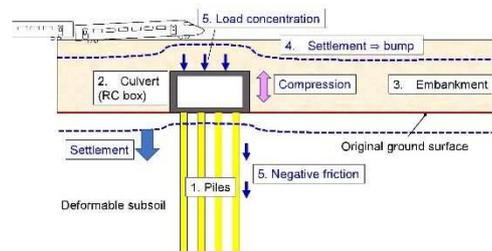
To ensure the advantageous features of RRR GRS structures

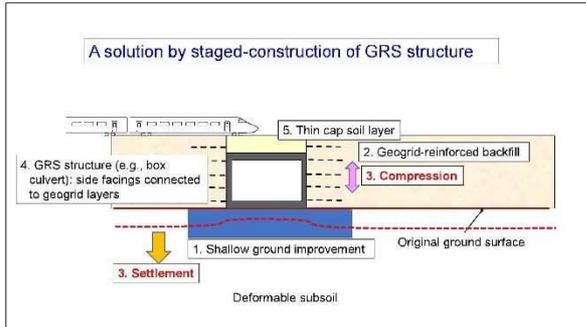
- (1) Full-height rigid (FHR) facing firmly connected to the densely arranged geogrid layers in a small vertical spacing (i.e., 30 cm) to enhance high performance as a composite.

- (2) Staged construction, firstly the construction of reinforced backfill to the full wall height using temporary facing units; then, after the deformation of the backfill and subsoil has taken place sufficiently, FHR facing is constructed by casting-in-place fresh concrete directly on the wall face, without occupying large space in front of the wall face.



Several serious problems with the box culvert crossing road/railway embankment on deformable subsoil constructed by the conventional method

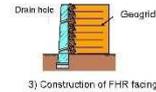




3) Three basic characteristic technologies of RRR GRS structures

To ensure the advantageous features of RRR GRS structures

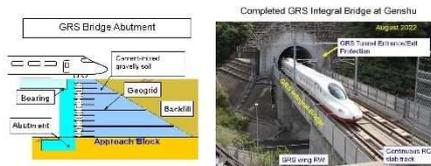
- (1) **Full-height rigid (FHR) facing** firmly connected to the densely arranged geogrid layers in a small vertical spacing (i.e., 30 cm) to enhance high performance as a composite.
- (2) **Staged construction**, firstly the construction of reinforced backfill to the full wall height using temporary facing units; then, after the deformation of the backfill and subsoil has taken place sufficiently, FHR facing is constructed by casting-in-place fresh concrete directly on the wall face, without occupying large space in front of the wall face.
- (3) **Geogrid layers having a very high durability against high pH**, as the geogrid is in direct contact with concrete.



4) Five core construction procedures of RRR GRS structures -1/2

- the minimum requirements to avoid serious troubles:

- (1) The use of geogrid having a very high durability against high pH (because of direct contact with concrete) and a high pull-out strength in the backfill and the concrete.
- (2) The use of backfill of high quality; good compaction; and confirmation of high quality of compacted backfill, essential for very small residual deformation



4) Five core construction procedures of RRR GRS structures - 2/2

(3) The use of temporary facing units that satisfy the contradicting requirements:

- a) flexible enough to accommodate the deformation of the backfill and subsoil caused by the construction of the backfill, and
- b) strong enough against the earth pressure by compaction forces and backfill weight.

- (4) Before casting-in-place fresh concrete to construct the FHR facing, the end of the settlement of the backfill and subsoil should be confirmed by continuously monitoring their settlement (i.e., staged-construction).
- (5) The FHR facing should be constructed in such that it is firmly connected to all the geogrid layers.



III-4 Discussions with inquiries and responses

III-4-1 Response to inquiry1

Queries on RRR Construction

JICA-NHSRCL-ADBI-JARTS Knowledge Sharing Workshop

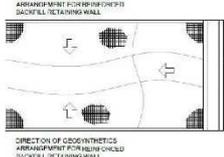
Response of RRR International

Dr G D Raju & Usha A. Larsen & Toubro

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LARSEN & TOUBRO

Queries - ABUTMENT



1. when the geosynthetic of cement approach block & back fill retaining wall overlap, the direction of roller for compaction shall be as per the arrow mark shown in fig 1 & Fig 2.

i.e perpendicular to abutment in Cement approach block till the backfill starts and perpendicular to retaining wall when it is only backfilling compaction.

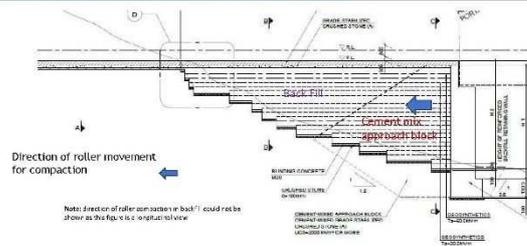
Please confirm our understanding

橋台前面工事を重複するセメント改良土は橋台壁面上に平行？

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Response of RRR International to Queries – ABUTMENT 2/2



Direction of roller movement for compaction

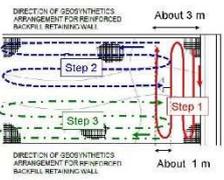
Note: direction of roller compaction in backfill could not be shown as this figure is a longitudinal view.

Fig 2: longitudinal view of Cement approach block & back fill

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Response of RRR International to Queries – ABUTMENT 1/2



Both of “geosynthetic-reinforced cement-mixed backfill for approach block” and “unreinforced / cement-mixed backfill” are compacted keeping the moving direction of roller in parallel to the wall face, starting from the immediately back of the wall face toward the inner place, as per the arrow mark shown in Fig. 1A.

The compaction starts from step 1 using a hand-operated compactor for a width of about 3 m from the wall face (before the construction of FHR facing), which is followed by steps 2 and 3, in which a hand-operated compactor is used in a width of about 1 m from the wall face, followed by compaction using a heavy roller at deeper places.

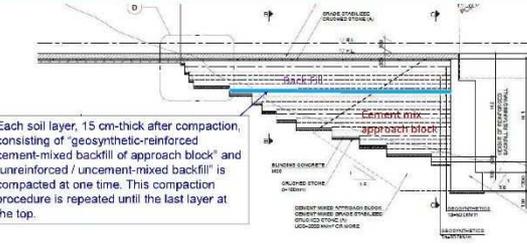
The compacted zones at steps 2 and 3 overlap the one at step 1 in a width of about 1 m.

Fig 1A

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Queries - ABUTMENT



Each soil layer, 15 cm-thick after compaction, consisting of “geosynthetic-reinforced cement-mixed backfill of approach block” and “unreinforced / cement-mixed backfill” is compacted at one time. This compaction procedure is repeated until the last layer at the top.

Fig 2A: longitudinal view of Cement approach block & back fill

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Queries - Retaining wall

4. For retaining wall height ≤ 3 m, whether N value/UCS criteria or K30 value criteria to be ensured for supporting ground?

Explanation of a scenario is provided in next slide

3.1.4 Supporting Ground

- When the height of reinforced backfill retaining wall is more than 3.0m, the supporting ground shall have minimum SPT-N value of 20 for sandy soil, minimum SPT-N value of 10 for cohesive soil, or minimum UCS value of 12.5MPa for rock. Minimum SPT-N value and UCS value, as applicable shall be ensured for a minimum continuous depth of 3.0m below the founding level.
- When the height of reinforced backfill retaining wall is equal to or less than 3.0m, N value of the supporting ground shall be more than or equal to 110 MN/m².

SPT-N	UCS (MPa)	Applicable Storage	
		Applicable	Storage
10-20	0.05-0.10	REINFORCED BACKFILL	REINFORCED BACKFILL
20-30	0.10-0.15	REINFORCED BACKFILL	REINFORCED BACKFILL
30-40	0.15-0.20	REINFORCED BACKFILL	REINFORCED BACKFILL
40-50	0.20-0.25	REINFORCED BACKFILL	REINFORCED BACKFILL
50-60	0.25-0.30	REINFORCED BACKFILL	REINFORCED BACKFILL
60-70	0.30-0.35	REINFORCED BACKFILL	REINFORCED BACKFILL
70-80	0.35-0.40	REINFORCED BACKFILL	REINFORCED BACKFILL
80-90	0.40-0.45	REINFORCED BACKFILL	REINFORCED BACKFILL
90-100	0.45-0.50	REINFORCED BACKFILL	REINFORCED BACKFILL
100-110	0.50-0.55	REINFORCED BACKFILL	REINFORCED BACKFILL
110-120	0.55-0.60	REINFORCED BACKFILL	REINFORCED BACKFILL
120-130	0.60-0.65	REINFORCED BACKFILL	REINFORCED BACKFILL
130-140	0.65-0.70	REINFORCED BACKFILL	REINFORCED BACKFILL
140-150	0.70-0.75	REINFORCED BACKFILL	REINFORCED BACKFILL
150-160	0.75-0.80	REINFORCED BACKFILL	REINFORCED BACKFILL
160-170	0.80-0.85	REINFORCED BACKFILL	REINFORCED BACKFILL
170-180	0.85-0.90	REINFORCED BACKFILL	REINFORCED BACKFILL
180-190	0.90-0.95	REINFORCED BACKFILL	REINFORCED BACKFILL
190-200	0.95-1.00	REINFORCED BACKFILL	REINFORCED BACKFILL

Volume 2, Dns 0300: Earth structure, section VI 2 (design requirements and criteria)

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Queries - Retaining wall

4. Below is a case presented for fixing of Retaining wall foundation:
While fixing founding depth for retaining wall, if Wall ht is > 3m, N value check done and the depth is fixed. (case 1). When the step is fixed (300 mm / 600mm) the wall ht becomes less than 3m (case 2) where $K_{30} > 110 \text{ kN/m}^3$ is not satisfied and may need deeper excavation. How to handle such situation on site. (refer next slide for more explanation)

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Response of RRR International to Queries - Retaining wall

In this figure provided as part of the queries, H denotes the thickness of the backfill, not the height of retaining wall. The queries are made on this definition. However, in Design requirements and criteria, the height H of retaining wall height is defines as shown at the left-end part of this figure. It seems that these queries may be made again based on this original definition of H.

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Queries - General

11. What is the allowable deviation/ tolerance of fill verticality. (such as ± 3 to 5 deg).
12. In Technical specs, Drains are mentioned as precast. Can the alternate option of Cast in-situ be considered?
13. After filling the final layer of backfill material / cement mixed approach block, do we have to wait for construction of roadbed.
If yes, what is the criteria to be followed?
14. Can the noise barrier gantry/Truck mounted crane be allowed to move on the constructed fill portion.
If yes, please provide guideline for SBC / pressure distribution that can be allowed.

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Response of RRR International to Query No. 11 1/2

11. What is the allowable deviation/ tolerance of fill verticality. (such as ± 3 to 5 deg).

[Response]

The allowable deviation of fill verticality at the temporary wall face before the construction of the FHR facing is 2 – 3 cm at the crest of the wall irrespective of wall height. It is not difficult to keep this tolerance by:

- 1) the setback technique (as described in the next page); and
- 2) continuous checking of the wall face verticality relative to a vertical reference at the end of compaction of every two soil layers in a total compacted thickness of 15 cm x 2= 30 cm.

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Response of RRR International to Query No. 11 2/2

Page 86 of PPT file: Key Construction Procedures and Their Proper Execution, prepared for Workshop, 27 March 2024

e) Compaction of Crusher Run and Backfill (continued)

When constructing a GRS retaining wall or a GRS abutment, each temporary facing units should be arranged with a proper setback (typically about 1 - 2 cm) relatively to the unit immediately below so that the alignment of the temporary wall face at the end of the construction to the full wall height is maintained vertical enough.

[Background]

This setback is to ensure the thickness of the full-height RC facing constructed by casting-in-place the fresh concrete over the temporary facing units indicated in the drawing. The arrangements of temporary facing units without a proper setback results in an inclination from the vertical of the temporary wall face that becomes larger at higher wall levels. Then, the concrete facing becomes thinner than the one specified in TS with this trend becoming stronger at higher levels of the wall.

To evaluate the amount of proper setback, the following on-site method is known to be effective. During a trial construction of GRS retaining wall (and/or a GRS bridge abutment), the ultimate cumulative lateral external displacement Δ at the front vertical face of a given temporary facing unit that would take place by the construction of the current soil layer and subsequent overlying soil layers is evaluated. To this end, at a couple of temporary facing units, the horizontal movement at the target arranged on the vertical front face of the temporary facing unit is measured before the start of the construction of the current soil layer and also at the end of the construction of each of the subsequent overlying five soil layers.

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Response of RRR International to Query No. 13

13. After filling the final layer of backfill material / cement mixed approach block, do we have to wait for construction of roadbed.
If yes, what is the criteria to be followed?

[Response] After filling the final layer of backfill material / cement mixed approach block and before the construction of FHR facing, you do not need to wait for construction of roadbed (i.e., gravel layer not including a RC slab; the RC slab is constructed after the construction of FHR facing). This is the ordinary practice when the supporting ground has been properly improved as necessary and the backfill is well compacted as required.

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Response of RRR International to Query No. 14 1/3

14. Can the noise barrier gantry/Truck mounted crane be allowed to move on the constructed fill portion.
If yes, please provide guideline for SBC / pressure distribution that can be allowed.

[Response] The answer is yes with completed RRR GRS RWs (after the construction of FHR facing). This practice is based on the followings;
1) the results of full-scale loading tests on RRR GRS RW described in Figs. 18 and 22 in Tatsuoka et al. (1992) (of which a pdf file is attached here).

Geosynthetic Reinforced Soil Retaining Walls, No. 342 © 1992 Balkema, Rotterdam, ISBN 90 619 0107 2
Permanent geosynthetic-reinforced soil retaining walls used for railway embankments in Japan

Tatsuoka
Faculty of Civil Science, University of Tokyo, Japan
O. Murata & M. Tazawa
Railway Technical Research Institute, Fukushima City, Tokyo, Japan

2) Experiences at the site (shown on the two page later).

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Response of RRR International to Query No. 14 1/2

In these full-scale loading tests, the base area of the loading footing is 1 m time 3 m (the width of test wall segment)= 3 m². So, a pressure q= 20 tonf/m² is equal to a load of 60 tonf in a 3 m-width. Within this load range, the wall deformation is very small, despite that the facing for these test GRS RWs is not steel-reinforced so could buckle at the lateral construction joints (note: the FHR facing for actual GRS RWs are all steel-reinforced).

It is to be noted that q= 20 tonf/m² far exceeds the design value (i.e., q= 3 tonf/m²).

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Response of RRR International to Query No. 14 3/3

At this site, a crane, of which the weight may be about 20 tonf, was supported by four footings, which are located very close to the FHR facing, without causing any trouble. The load at two footing loads is about 10 tonf at each side. The wall deformation by this load (q= 3.3 tonf/m²) was negligible in the full-scale loading tests described in the preceding page. The total weight of a crane mounting noise barrier may be about 20 - 30 tonf. It is estimated that the wall deformation by this load is negligible.

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Queries

Clarification on Earth structures in Cutting

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Response of RRR International to Queries

1. Definition of Natural ground

It seems that "Natural ground" to which the soil nailing technology is applied in this project could be either "natural origin ground" or "artificial fill/embankment".

The soil nailing technology is used to stabilize existing ground or slope, which is either natural origin ground or artificial fill, with cutting or without cutting, but always without filling.

So, in this project, "natural ground" may imply "existing ground or slope".

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III-4-2 Response to inquiry2

Responses to some Inquires from the Indian delegates, 19 – 22 May 2025:
13 June 2025
RTRI and RRR-I

- **Timing of installation of drain pipes at the wall face:**
Explained on pages 2 & 3.
- **Monitoring of the settlement of the supporting ground:**
One of the typical cases is shown in Figures D on pages 4 – 7. It is anticipated that similar behaviour will be observed in the HSR projects in India.
A case presented in Figs. C on pages 8 - 14 is rather exceptional in that the supporting ground is very soft waste landfill where the soft soil supporting a RRR GRS wall was improved by cement-mixing-in-place.
- **Arrangements of geogrid in the approach fill of RRR GRS bridge abutment having wing RWs:**
Explained on pages 15 - 18.

Note: This document was prepared with help of Prof. Watanabe, K. (University of Tokyo) and Tatsuoka, F. (Prof. Frenelus, University of Tokyo and Tokyo University of Science)

1

■ Timing of installation of drain pipes at the wall face

The following method is described on page 129 of *Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures*

- Water drain pipes shall be installed as drainage work to prevent a rise in the pore water pressure in the embankment. Polyvinyl chloride pipe (standard ϕ : 65 mm) shall be used for such water drainage pipe. At the rear end on the embankment side of the water drain pipe, a soil crum-out prevention material (choices: approximately 10 mm) shall be installed. Furthermore, water drain pipes may change their direction at the time of compaction of the temporary holding at the wall face with a result that an adequate drainage inclination will not be maintained. To avoid this, as shown in Fig. 3.2.9-1, there is a method available in which a socket that is a little larger than the water drain pipe is installed in advance at the time of stacking gravel bags and the water drain pipe is inserted into it at the time of assembling the concrete form.



Figure 3.2.9-4 Typical arrangement of drain pipe



Figure 3.2.9 Installation of drain pipes

2

According to the method described in the manual (as copied on the immediately preceding page), a socket in which the water drain pipe is installed in advance at the time of arranging gravel bags or welded steel fabric containing gravelly soil. The water drain pipe is inserted into the (as shown in Photo 3.2.9) socket at the time of assembling the concrete form.

However, at the Ioka site, this standard method was not followed, but the following modified method is employed:

- 1) Welded steel fabric containing gravelly soil were arranged before installing the drain pipes. So, we saw the wrapped-around wall face without drain pipes, unlike the one shown in Photo 3.2.9.
- 2) Each drain pipe will be arranged in a hole made by cutting the front face of the geogrid wrapping.
- 3) Then concrete form will be assembled before casting-in-place fresh concrete to construct FHR facing.

This modified method needs rather delicate work when compared with the standard method (described in the immediately preceding page). The JRJT and the contractor decided to adopt the modified method considering that the modified method is better in the constructibility while the modified method is feasible as well-trained and experienced technicians are available.

We recommend to follow the standard method for the HSR projects in India this time, considering that these projects are the first case of the construction RRR GRS structure in India. The modified method may be adopted only after confirming a sufficient high constructivity.

3

■ Monitoring of the settlement of the supporting ground:

Reconstruction of highway embankment in Yamagata, 1985

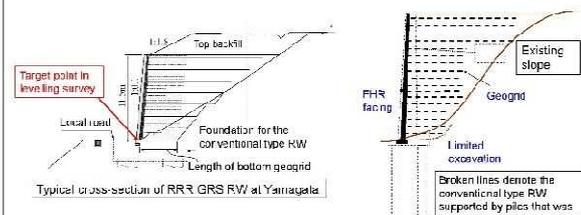


Fig. A-1



Fig. A-2

5



Fig. A-3

6

The site is located along a natural slope in an mountain area, where the supporting ground is relatively stiff.

The settlement of the supporting ground was measured at the top of the embedded part of the facing by the levelling survey (Fig. A-1).

- The following trends may be seen:
1. Most of the settlement took place during the construction of the reinforced backfill and the overlying unreinforced top backfill.
 2. The settlement rate became very small about 50 days after the end of embankment work.

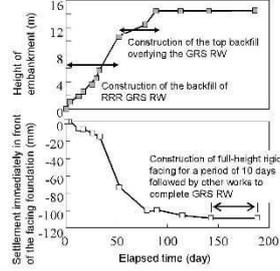


Fig. A-4

7

RRR GRS RW with a decorative masonry facing on a waste landfill for an open-air theater in a park, 2005



Fig. C-1

RRR GRS RW with a FHR facing

Tei et al. (2006) I/CG Yokohama

8

Staged construction

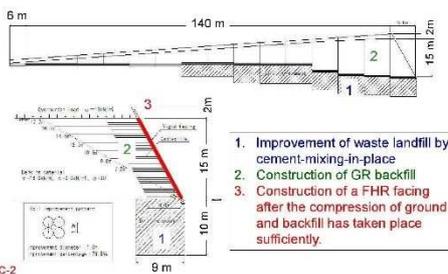


Fig. C-2

Tei et al. (2006) I/CG Yokohama

9

Installation of horizontal drains



Fig. C-3

Tei et al. (2006) I/CG Yokohama

10

Wall under construction



Fig. C-4

Tei et al. (2006) I/CG Yokohama

11

Completed GR backfill (before the construction of a FHR facing)



Fig. C-5

Tei et al. (2006) I/CG Yokohama

12

In this case, due to soft ground condition, it took some long duration for the ground settlement to become small enough for the start of FHR facing.

It is not known whether such a case as this will not be encountered in the current HSR projects in India.

If such a case is encountered and if it is required to shorten the waiting period, the application of a preload on the crest of the reinforced backfill is very effective.

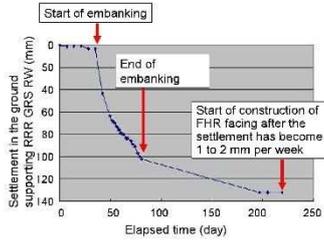


Fig. C-6

Tei et al. (2006) #/CG Yokohama

Completed wall



Fig. C-7

Tei et al. (2006) #/CG Yokohama

■ Arrangements of geogrid in the approach fill of RRR GRS bridge abutment having wing RWs:

RRR GRS bridge abutment, 21th May 2025, West Otamoi-river Site



The reasons why geogrid B in the wing RRR GRS RW is noticeably shorter than geogrid A, which is the reinforcing member (i.e., the basic layers of geogrid) in the bridge abutment are as follows:

- 1) The FHR RC facing as the abutment structure directly supporting the bridge girder is designed by the stability analysis in which the passive earth pressure that may be activated in the backfill filled in a space from the bottom of the facing (i.e., the current ground level after excavation, seen at this stage) to the final ground level (after this backfilling) is ignored for a conservatism, prepared for the loss of this backfill in the future. The reinforcing geogrid layers A are arranged in the ordinary way where the arrangement of geogrid layer starts from the bottom of the FHR facing (which is the current ground level after excavation).

(to be continued)

(continued)

2) On the other hand, the FHR RC facing of the wing RRR GRS RW is designed by the stability analysis in which the passive earth pressure that may be activated in the backfill filled in a space from the bottom of the facing (i.e., the current ground level after excavation, seen at this stage) to the final ground level (after this backfilling) is effective. This effectiveness is ensured by careful backfilling while it can be reasonably assumed that the surrounding level grounds will be persistent. Geogrid layers B are arranged in such that the reinforced backfill with a height of only 2m, between the excavated ground level and the final ground level is stable until the backfilling is made, which is followed by the start of the construction of the backfill from the final ground level. That is, it is assumed that, with the completed wing RRR GRS RWs, a 2m high geogrid-reinforced backfill below the final ground level is treated as part of stable supporting ground.

Geogrid layers in the reinforced backfill above the final ground level are arranged in the ordinary way, where the basic geogrid layers are much longer than geogrid B. The length of the basic geogrid layers is the largest value among: a) 35 % of wall height; b) 1.5 m; and c) the length required for residual wall deformations to be lower than allowable values, evaluated for over-turning & lateral sliding by "the Newmark method based on the TW stability analysis" and for shear deformation of reinforced zone. The relevance of this geogrid arrangement is confirmed by the stability analysis of wing wall sections.

(to be continued)

(continued)

This is one of the possible variations of the structure details of RRR GRS structures. In any case, each variations should be examined by stability analysis, reviewed by engineers that have sufficient experiences with the design and construction of RRR GRS structures.

III-4-3 Response to inquiry3

Framework of Technical Support for Construction of RRR GRS RWs and Bridge Abutments of HSR in India

13 June 2015
RTRI
RRR-International

Attachments: three PDF files about method statement for Construction

1) The technical support by RTRI and RRR-I, probably also by Yebisus (the representative, Mr. Ebii, Noriaki), will be made by: a) E-mail exchanges; b) WEB meetings; c) on-site interactions; and d) other relevant means.

2) Confirmation of the site where the on-site technical support is to be made:
When the on-site technical support that is described in this note is made at C4-Es-2, where a RRR GRS Bridge Abutment will be constructed, basically the on-site technical support for RRR GRS RWs and Bridge Abutments at other sites may not be necessary. When necessary, on-site technical support may be performed also at another site (or other sites) .

3) Preparation of Method statement for construction of RRR GRS RWs and Bridge Abutments for HSR in India (“Method statement for construction” in short)

To determine the items and contents of the technical support, it is necessary to confirm the contents of Method statement for construction by all the related parties (including NHRCL, L&T, RTRI and RRR-I).

In this respect, RRR-I received the following document prepared by L&T and via NHRCL and RTRI in the beginning of October 2024: “*Original Method Statement for Construction of RE Wall Oct 2024*” (File No. 1).

We reviewed this document and sent back to L&T via RTRI and NHRCL in the beginning of November 2024 the following document, where our comments were indicated in red letters:

“*FT 29 Oct 2024 Method Statement for Construction of RE Wall (reviewed by RTRI&RRR-I)*” (File No. 2)

Subsequently, we reviewed the above document (File No. 2) and added a couple of comments (indicated in red letters painted in yellow) in the following document: “*Commented June 2025 Method Statement for Construction of RE Wall (reviewed by RTRI&RRR-I)*” (File No. 3).

In any case, we need to discuss on the contents of this document (File No. 3). In particular, RTRI and RRR-I like to know the opinion by related Indian parties (NHSRLC and L&T) on the comments by RTRI & RRR-I indicated in File No. 3.

4) List-up of the items and contents of technical support

It is necessary to make the list of the terms with contents of the technical support based on the discussions and confirmation described in term 3) above,

The followings are among the notions that we need to take into account when making the above-said list.

- a) At least, two times of on-site technical support may be necessary. The first one may start sometime before the start of the construction of the first soil layer (i.e., the bottom soil layer) of reinforced backfill and will continue until sometime after the end of the construction of the third or fourth soil layer. This on-site technical support will be one of the most important steps while most efficient for the confirmation of construction details.
This on-site technical support may include the on-site confirmation of the measuring method of the coefficient of vertical subgrade reaction by Portable Falling Weight Deflectometer tests, likely by using a device provided by Tokyo Sokki.
- b) This on-site technical support may start sometime before the start of the construction of the foundation of the FHR facing. Although this on-site technical support is effective, this could be omitted if the time is not allowed.
- c) The second on-site technical support will be made separately from the first one. The second one may start sometime before the start of the construction of the FHR facing, in which the following construction steps will be included:
 - arrangements of drain pipe;
 - arrangements of concrete form and separator;
 - arrangements of external concrete form; and
 - casting-in-place concrete.
- d) The proper preparation of cement-mixed backfill and its proper compaction in the field is very important. To this end, the following preparation works shall be started sufficiently

before the start of the construction of the approach block (i.e., sufficiently before the first on-site technical support):

- (1) Determination of the mixing proportion of cement-mixed soil by
 - i) selecting a proper backfill type;
 - ii) performing laboratory compaction tests (Modified Proctor) to find the optimum water content and the maximum dry density; and
 - iii) performing a series of unconfined compression tests on specimens that will be cured for a period of 28 days to confirm whether required strength as specified can be obtained.
- Development and determination of the relevant method of uniform mixing of cement-mixed soil (i.e., either mixing using mechanical equipment at site or producing in a concrete batching plant and transporting to the construction site). The details of field compaction (the type of compaction equipment and the number of passing) that can achieve the specified compacted dry density at specified molding water content shall be determined by performing full-scale trial compaction tests.

III-4-4 Response to inquiry4

LARSEN & TOUBRO LIMITED METHOD STATEMENT FOR
 H C I C CONSTRUCTION OF REINFORCED
 Mumbai-Ahmedabad High Speed Rail BACKFILL RETAINING WALL &
 (Package No. MAHSR –C-4) REINFORCED SOIL BRIDGE ABUTMENT
 MAHSR/L&T/PKG/CA/QA/QC/MS/02476,
 Rev 01

TABLE OF CONTENTS (Provisional)

**This numbering and page Nos. may not be consistent with those in the main text so should be corrected.*

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2. SCOPE

This Method Statement details the procedure proposed for Construction of Reinforced Backfill Retaining Wall & Reinforced Soil Bridge Abutment, as per technical specification and approved drawings.

3. REFERENCES

- Clause Nos. 4.0 of Division 03000, Employer's Requirement (Technical Specifications) (Part VI-3, Volume 3).
- Division 03000, Employer's Requirement (Design Requirements & Criteria) (Part VI-2, Volume-2).
- Cross Section Drawings.
- Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures.

4. RESOURCES

4.1 Manpower

Responsibility Matrix.

```

    graph TD
      PD[Project Director] --> PM[Project Manager]
      PM --> ESE[Execution/Site Engineer]
      PM --> S[Surveyor]
      PM --> QME[Quality Manager/Engineer]
      PM --> SME[Safety Manager/Engineer]
      PM --> PME[P&M Engineer]
    
```

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4.1.1 Project Director

The Project Director will be responsible for overall execution of work within the stipulated time and as per technical specification with safety and Quality.

4.1.2 Project Manager

- Reports to Project Director
- Responsible for ensuring implementation of Method statement & ITP's.
- Ensure implementation of Control measures & safety norms as per HIRA at workplace.
- Plan resources in his area and make them available on site.
- Interact with the Engineer for approvals.
- Responsible for handing over of completed section for next process to the Engineer.
- Keep track of Internal/Customer complaints on quality, their compliance, control on repetitions and guide/support the execution team under him.

4.1.3 Site Engineer

- Reports to Section-in-charge
- Responsible for execution of works as per Method statement & ITP's.
- Responsible for executing the works as per approved and latest drawings.
- Responsible for arranging and attending all Internal and Client's Inspections against RFIs.
- Cross check availability of resource before start of operations.
- Follow approved work method statements and interact with QA-QC/Shift/Section-In-Charges, if any change or revision is needed in the procedure that enhances the quality of construction.
- Implementation of safety norms as per HIRA.
- Interact with surveyor, QA/QC team and EHS team.
- Responsible for documentation and reporting.

4.1.4 Surveyor

- Report to Section-In-Charge
- Ensure only calibrated survey instruments are used during construction.
- Responsible for marking levels and fixing coordinates of the alignments.
- Responsible for ensuring alignments as per approved drawings.
- ~~Responsible for marking excavation pit boundaries.~~
- ~~Responsible for safeguarding TBMs and center-line pegs/spikes.~~

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~~g—Responsible for calibrating and recalibrating TBMs and center-line pegs/spikes.~~

*Terms e, f and g are for tunneling work not for GRS structures.

4.1.5 QA/QC Engineer

- Reports to QA/QC-In-Charge.
- Responsible for testing and approval of materials.
- Ensure only approved materials are being used in construction.
- Coordinate/Supervise with Site Execution/Safety/Survey for ensuring the construction works are as per approved method statement and ITP.
- Responsible for inspection of material and works as per method statement and ITP.
- Responsible for testing's as per technical specifications and Method Statement and ITP.
- Responsible for ensuring all inspection reports as per ITP.
- Coordinate with the Engineer on quality related issues.
- Ensure shift handover and takeover of the QA/QC activities.
- Identify and raise non-conformances, in case of works/activities not meeting the specification requirements and ensure implementation of correction and corrective action to close the NCRs.
- Suggest and implement improvements to product quality.

4.1.6 P & M Engineer

- Reports to P&M-In-Charge
- Responsible for periodic & incidental maintenance of site equipment for smooth and continuous operations.
- Attending incidental breakdowns immediately.
- Ensure lock-out and tag-out system while attending breakdown and/or maintenance.

4.1.7 EHS engineer

- Reports to EHS-In-Charge
- The HSE officer is responsible to examine the risk / hazard for this activity and to prepare a plan to eliminate the risk/hazard and to protect the safe environment & ensure workmen safety.
- Involves regular pep-talks and periodical demonstrations of safety practices at site.
- Help to provide necessary safety materials at the work location as per requirements.
- Ensure Implementation of EHS system at site.
- Ensure implementation of safety norms as per HIRA.
- Ensure the site is illuminated sufficiently in case night work is carried out.
- Coordinate with site administration, first-aid, Doctor, and hospitals during emergency.

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4.2 EQUIPMENT

The list of equipment's required for the construction of Earth Retaining Wall & Bridge Abutment is given below

Sl. No.	Equipment	Qty.	Remarks
A. Main Equipment			
1.	Excavator/JCB	1 Nos	
2.	Vibratory Roller	1 Nos	
3.	Plate Vibrator	1 Nos	
4.	Dumpers	As required	
5.	Transit Mixer (6.0 cum)	As per requirement	
6.	Concrete Pump	As per requirement	
7.	Boom Placer	As per requirement	

4.3 MATERIAL LIST

S.No	Material	Requirement	Remarks
1.	Backfilling Material	Clause 4.4.1 of MS	
2.	Geosynthetics	Tensile Strength Ta -30 Tensile Strength Ta -60	Reinforcing Materials as per drawing and TS.
3.	Geo Textile	IRC SP-59/As per drawing	To drain out water from the surface and tracks without causing any damage to structure.
4.	Welded Wire Mesh	IS 1566/As per drawing	Temporary Holding
5.	Grade Stabilized Crushed Stone Grade A	As per TS /As per drawing	Drainage Layer below concrete roadbed.
6.	Grade Stabilized Crushed Stone Grade B	As per TS /As per drawing	Drainage Layer
7.	Cement Mixed Graded Stabilized Crushed Stone Grade A	As per TS /As per drawing	Approach Block
8.	Perforated Reinforced Concrete pipe with Non-Woven Geo Textile	IS 7319/As per drawing	Drainage Pipe
9.	Geo Composite Drain	As per TS /As per drawing	As applicable as per

4.4 MATERIAL

4.4.1 Backfill Material

Backfill Material shall be made of a good quality, free draining, granular and/or selected fill and shall be mechanically compacted. The Backfill material shall consist of sound, tough, hard, durable particles of free draining sand gravel material, soil, morrum, gravel, or crushed sand. Such material shall be free of organic material, clay balls or other deleterious matter. Backfilling shall be done with inorganic materials, obtained from the excavation or borrow pits. The material used for back filling shall conform to the provisions of IS 1498.

The following are unsuitable as backfill materials.

1. Bentonite, acid clay, sulphuric clay and other expandable soil or rock.
2. Serpentinite, mudstone with a slaking rate of 50% or more, and other rock that has been remarkably weathered by water absorption expansion.
3. Highly organic soil and other highly compressible soil.
4. Frozen soil.

Table 3 –Test for Backfill Material

The testing of backfill material for earth retaining structure shall be subjected to soil tests shown below.

Sl. No.	Item	Standard	Remarks
1.	Grain Size Analysis	IS: 2720 (Part 4)	
2.	Water Content Test	IS: 2720 (Part 2)	Natural State (Ground)
3.	LL & PL	IS: 2720 (Part 5)	
4.	Density of Soil	JIS A1214-2013/ IS: 2720 (Part 28)	Natural State (Ground)
5.	Density of backfill soil	IS: 2720 (Part 8)	
6.	Density test of soil particle	IS: 2720 (Part 28)	Compaction
7.	Angle of Internal Friction	IS: 2720 (Part 13)	Direct shear test

Table -4: Specification for backfill material

Sieve Size	Percentage Passing
75mm	100 %
425 microns	0-60 %
75 microns	Less than 15 %
Pl s 6	
Angle of Internal Friction - :? 40°	

4.4.2 Grade Stabilized Crushed Stone for Drainage Layer

i. Grade Stabilized Crushed Stone (A)

Specifications of the grade stabilized crushed stone for the roadbed and approach block etc. shall be such that it is a well-graded sandy gravel layer of adequate hardness. Particles size gradation curve shall be more or less within enveloping curve of material as shown in Figure-2. The properties and grading percentage shall be within the range as given in Table-5 & Table 6.

Table-5: Grade stabilized crushed stone shall also satisfy the following criteria:

Property	Requirement	
Uniformity Coefficient Cu & Coefficient of Curvature Cc	Cu > 7 and Cc between 1 and 3.	See Note
Fine (passing 75 microns)	3 % to 10 %.	
Los Angeles Abrasion value	< 35 %.	
CBR value	The minimum required Soaked CBR value 80% of the grade stabilized crushed stone material compacted at 95 % of MDD.	

Note:

Uniformity Coefficient (Cu) which is a measure of the uniformity of grain size in the soil and is defined as the ratio of the 60% finer size D60 to D10.

that is $Cu = D_{60} / D_{10}$

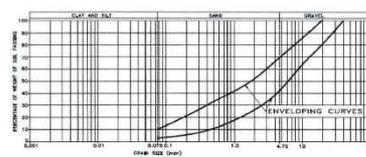
Coefficient of Curvature (Cc) is a value that can be used to identify a poorly graded soil.

$$C_c = \frac{(D_{30})^2}{D_{10} \cdot D_{60}}$$

Table-6 Grading Percentage of Grade Stabilized Crushed Stone (A)

SL	IS Sieve Size	Percent Passing (by weight)
1.	40 mm	100
2.	20 mm	80 - 100
3.	10 mm	63 - 85
4.	4.75 mm	42 - 68
5.	2 mm	27 - 52
6.	600 micron	13 - 35
7.	425 micron	10 - 32
8.	312 micron	6 - 22
9.	75 micron	3 - 10

Fig-2: Enveloping Curves for Grade Stabilized Crushed Stone (A)



4.4.3 Grade stabilized crushed stone (B)

Specifications of the grade stabilized crushed stone for the drainage layer etc. shall be such that it is well-graded sandy gravel layer of adequate hardness and grading percentage shall be within the range as given in Table-7.

Grade stabilized crushed stone shall also satisfy following criteria:

- a) Los Angeles Abrasion value < 35%.

Table-7 Grading Percentage of Grade Stabilized Crushed Stone (B)

Sl.	IS Sieve Size	Percentage Passing (by weight)
1.	53 mm	100
2.	37.5 mm	95 - 100
3.	19 mm	50 - 80
4.	4.75 mm	15 - 40
5.	2.36 mm	5 - 25

4.4.4 Material for Cement Mixed grade stabilized crushed stone (A) for Approach Block

- i. Cement OPC 53
- ii. Grade Stabilized Crushed Stone (A)

The grade stabilized crushed stone shall comply grade size distribution curve appended as clause 4.4.2, grade stabilized crushed stone (A).

a. Mix Design

Determine the mix design of treated soil by the following procedure.

- i. Determine the optimum water content ratio and the maximum dry density ρ_d max, of the soil/mix by laboratory compaction tests (Modified Proctor).
- ii. Add the optimal amount of cement to the crushed stone and prepare unconfined compression test specimen (D150 x H300mm) satisfying the dry density ρ_d which is **at least** 95% of maximum dry density by Modified Proctor.

- iii. In addition to the above, also prepare specimens with 2% more cement and 2% less cement.
- iv. The unconfined compression test shall be carried out as per IS:516.
- v. The amount of cement shall be decided corresponding to the design strength mentioned in the Drawings, by establishing the relationship between the amount of cement and the unconfined compressive strength.
- vi. Three test specimens shall be prepared for the sample having the same cement content. Compressive strength of a sample is defined as the average value of compressive strength of the three test specimens.

Table-8: Approach block shall also satisfy the following criteria:

Properties	Requirement
Material	
Cement Mixed Stabilized Crushed Stone	Approved Mix Design
Uniaxial Compressive Strength In 28 days, age	≥ 2000 kN/m ² (2 MPa)
Relative Compaction	Average C
Average Value	$\geq 95\%$
Lower Limit Value	95 % by Modified Proctor (according to TS).

4.4.5 Geo Synthetic

Geosynthetic is a general classification for all synthetic material used in geotechnical engineering applications. It includes geotextiles and geo-nets.

The geosynthetics for reinforced concrete wall shall have the proven tensile strength for earth retaining structure stability, durable and resistant against weathering, creeping, and have proven long working life expectancy. Geosynthetics shall be bonded biaxial geogrid.

The geosynthetics shall have the tensile strength mentioned in the Drawings. The original yarn of the geosynthetics shall also satisfy the following quality standards:

Table 9: Properties of Geosynthetic Materials

Geosynthetics - Geosynthetics shall be bonded biaxial geogrid.		
Properties	Requirement as per TS	Remarks
Tensile Strength of Geosynthetics, T_a (kN/m)	$T_a \geq 30$ kN/m & $T_a \geq 60$ kN/m	
Properties of Original yarn of the geosynthetics		
Tensile strength	More than 4.0cN dtex	JSL 1013
Elastic Ratio	More than 150cN dtex	JSL 1013
Creep Deformation Ratio	Less than 4.0% after 100 days at 10% of the breaking load at room temperature.	HSK 7115
Alkali Resistance Ratio	More than 90% of strength retention after soaking 1000 hours in saturated calcium hydroxide solution at 50°C.	
Stitch length	15mm to 30mm.	Yarn shall be coated PVC

4.4.6 Geotextile

Using a geotextile sheet to prevent the spilling out of backfill in a reinforced soil bridge abutment and backfill retaining wall construction. Geotextiles act as a filter and separator;

Geotextile Sheet shall have material characteristics as per Table- 10.

Table-10: Requirement for Geotextile Materials

Properties	Requirement as per Drawing	Remarks
Weight	300 gsm (min)	As per TS
Permeability Coefficient	$\geq 1 \times 10^{-3}$ m/sec	As per drawing

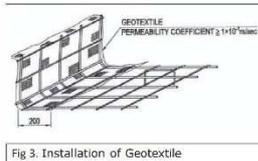


Fig 3. Installation of Geotextile

4.4.7 Welded Wire Mesh: Shall be as per drawing.

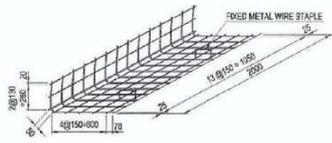


Fig 4. Welded Wire Mesh

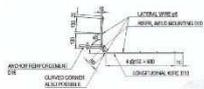


Fig 5. Welded Wire Mesh Cross Section

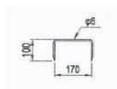


Fig 6. Metal Wire Staple

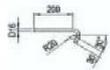


Fig 7. Anchor Reinforcement

4.4.8 Drainage pipe.

Perforated reinforcement concrete pipe 300 mm diameter wrapped with Non-Woven Geotextile shall conform to IS 7319 or Equivalent.

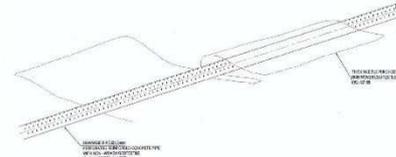


Fig 8. Perforated reinforcement concrete pipe

5.0 METHODOLOGY FOR CONSTRUCTION OF REINFORCED BACKFILL RETAINING WALL & BRIDGE ABBUTMENT.

Construction flow Chart



6.0 WORK PROCEDURE

Constructing Reinforced Soil Bridge Abutment & Reinforced Backfill Retaining Wall involves several steps and specialized techniques. The typical process involved in constructing the Reinforced Backfill Retaining Wall and Reinforced Soil Bridge Abutment and has been illustrated below.

6.1 Site Preparation:

a) All harmful obstructions and any objectionable material, plants, roots of trees, and any obstacles that may impede excavation work shall be removed from the supporting ground of the wall before the start of the construction works.

b) Ensure adequate access to construction equipment and materials.

6.2 Survey and Layout:

a) Conduct a detailed survey to mark the layout of the retaining structure as per the drawing.

b) Install reference points and markers to guide construction.

6.3 Excavation and Construction of Foundation:

The existing slope shall be bench-cut as per drawing to attain final excavation profile. The range of the execution of such bench-cutting shall be such that it will be possible to lay the geotextile reinforcement within the reinforced zone as per drawing.



Fig 9. Excavation and Construction of Foundation

- a) The slope of the Excavation shall be maintained as per the drawing, to prevent any collapse.
- b) The founding level of reinforced concrete wall/abutment from the ground surface shall be maintained as per drawings.
- c) Excavation for starter concrete below the existing ground level as per drawing shall be carried out. Below the founding level, a layer of blinding concrete (M20 Grade) supported by thick crushed stone layer shall be provided as per approved drawings.
- d) The line and level of foundation preparation shall be as per drawings.
- e) Over the PCC, the starter of suitable height shall be cast. Further, the construction of the main part of the RC facing is carried out **after the completion of the construction of the geotextile-reinforced-backfill**, after the end of sufficient deformation and settlement of the geosynthetic-reinforced backfill caused by its construction to the full-height.

6.4 Testing for Supporting Ground

6.4.1 Testing of Existing Ground for Backfill & Retaining Wall:

- a) Where ground condition is specified in terms of Standard Penetration Test (SPT) in the Drawings, the SPT test shall be conducted instead of Plate load test at the Centre of tracks. The test shall be done at an interval of every 30m, including at least the one at, or near, the location where the RC facing is to be constructed.
- b) If the founding strata is not found suitable, the unsuitable layers shall be removed and replaced with good soil as per designer recommendations. The depth of excavation and removal of existing unsuitable layers shall be as per designer recommendations (or)

What is the meaning of (or)?

- c) The Ground Improvement shall be carried out in accordance with Div 3000 – Sec VI-2 ER(DFM), and Cl 8 of Div 3000 Sec VI-3 ER(TS) and as per Drawing no. SD-JIC-C03-DRW-ALL-ETS-MD1-00001.

6.4.2 Testing of Existing Ground for Abutment:

At least one plate load test shall be carried out for every abutment at the center of tracks. The bearing of capacity of the supporting ground condition for abutment shall be at least 1800 KN/m².

6.5 REINFORCED BACKFILL RETAINING WALL

After testing and clearance of existing ground level, suitable back fill materials shall be filled in layers not more than 150mm thick, spread, and compacted.

The nominal maximum size of the aggregate shall be 20mm in case crushed stone are to be used as backfill for earth retaining structure. Large size crushed stone aggregate shall be distributed uniformly inside, all over the backfill for earth retaining structure ensuring no voids are formed. **However, large size crushed stone aggregate shall not be used in the top 1m layer of the backfill for earth retaining structure.**

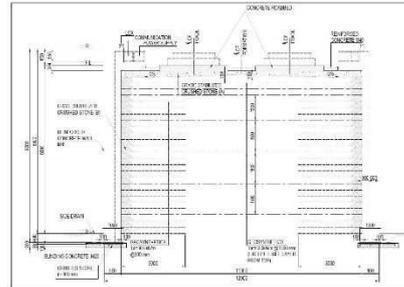


Fig 10. Reinforced Backfill Retaining Wall

6.5.1 Installation of Geosynthetic Reinforcements, Temporary holding Wire Mesh:

- a) Prior to backfilling for each soil layer with a total compacted thickness of 300mm, the geosynthetic, then geotextile & wire mesh shall be laid to the width as per drawing.
- b) Geosynthetic and Geotextile & wire mesh shall be placed flat at every 300mm in the vertical spacing **on each** at the shoulder of each 300mm-thick compacted soil layer and as per approved drawing.
- c) Laying of Ta-30 Grade Geosynthetic material **at each 300mm layer**, at a vertical spacing of 300mm, extending 3000mm in length or as per drawing. Ta-60 Grade Geosynthetic material **at each 1500mm layer**, at a vertical spacing of 1500mm, covering the full width of geosynthetic-reinforced backfill, and as per the approved drawing. The position of Ta-30 & Ta-60 geosynthetic material shall be as per the approved drawing.
- d) Keeping extra length of 800mm= 300mm (vertical) and 500mm (horizontal) for folding and extending the geosynthetic to wrap-around the top of the 300mm thick layer as mentioned in the drawing.

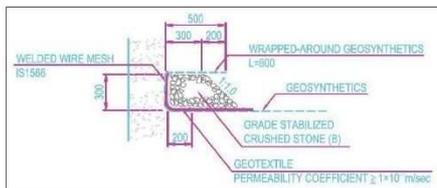


Fig 11. Geosynthetics Wrapping

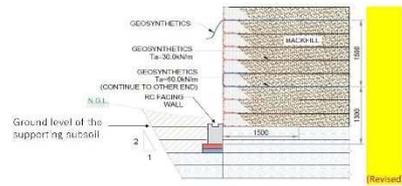


Fig 12. Typical arrangement of Geosynthetics (note: the embedded bottom part of FHR facing (shown in this figure) is constructed prior to the construction of reinforced backfill. The top level of this part should be the same as the bottom of the reinforced backfill (i.e., the ground level of the supporting subsoil)



- e) The geosynthetic shall be placed in transverse direction to the wall face (i.e., in transverse direction to the track for GRS RWs and in parallel direction to the track to GRS Bridge Abutment) and in such manner that there will be no extreme unevenness or gap. Special care shall be taken for direction of laying geosynthetics. Fig. 12 shows a typical arrangement of geogrid layers for reinforcement.

- f) The Geosynthetic shall be laid by overlapping it by **100mm-at-the-joints-in-transverse direction** a width of 100mm in the transversal direction along the joints continuing in the principal direction and as per specification and drawings.

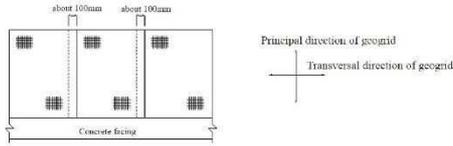


Fig 13. Geosynthetic overlapping

Fig 14.

- g) The L hooks required to be connected with RC wall reinforcement shall be provided along with the wire mesh as per the approved drawing (Please refer Fig.7).
- h) The drainage pipe with diameter not less than 6cm shall be placed at every 2-4m² of RC wall surface as per drawings. The drainage layer shall be placed supporting / using crushed stone at the backfill of walls as shown in the drawing (Please refer Fig.15).
- i) The mouth of drainage pipe / Weep hole in the back fill side shall be covered with **10mm** 10mm thick Geotextile (Please refer Fig.15).

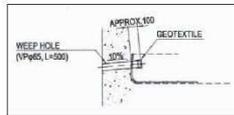


Fig 15. Weep Hole

- j) As applicable, Installation of Centre drain system at required level as per drawing.

6.5.2 Backfilling and Compaction

- a) After laying geosynthetic to the length as per drawing, the back fill material shall be uniformly spread and compacted.
- b) The back fill material shall be dumped and graded to a total thickness, **consisting of two 15 cm-thick compacted lifts**, not more than 300mm per soil layer between vertically adjacent geosynthetic layers. **At the ends of the backfill portion** At the area (approximately 1m wide) on the wall face side at the edge of the backfill portion, graded stabilized crushed stone (B) shall be laid **at the retaining wall area** to the width as specified in the approved drawing.
- c) To achieve better compaction and results, the back fill shall be laid in 150mm layer thick, spread, and compacted to achieve desired results. However, the testing of back fill will be done for every 300mm thick layer.
- d) The compaction of backfill layers in central main portion shall be done using 8-10 ton vibratory rollers or using mini roller depending upon the site condition. At the edge portion (Approx. 1m wide) near RC Wall, shall be compacted using plate vibrator only.



Photo 3. Compaction by plate vibrator



Photo 4. Compaction by roller/mini compactor

- e) The density for back fill material shall be tested either by sand replacement or by nuclear density gauge. After completion of compaction and satisfactory testing, the next layer of backfill material at the **center** central main portion and the crushed stone Grade B at the ends shall be laid **for a thickness of not more than 300mm as per drawing in 3 layers (150mm each)** in two sub-layers (150mm each) for a total thickness of not more than 300mm as per

drawing.

- f) The above process shall continue for each layer up to the required height. The width and the grade of **geotextile** geosynthetic (Ta30 & Ta60) shall be strictly kept as per drawings).
- g) The top 300mm of the back fill shall be laid and compacted with Grade stabilized crushed stone (A) as per drawing after construction of RC wall. **Density test for the top layer of back fill shall be using plate load test to achieve required K30 value.** Plate loading tests (typically by the portable falling weight deflectometer tests) to confirm required K30 value shall be performed on the top layer of backfill.
- h) Prior to starting compaction, **mock-up** full-scale trial compaction tests shall be done to monitor settlement based on no. of passes of the roller. Sketch to monitor settlement / compaction thickness is as shown below in Fig.16.

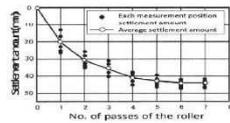


Figure-16 Example of Settlement Measurement Record.

6.5.3 Testing for Backfill Compaction (Testing Location for K30 Value)

On the finished surface at the upper backfill layer of the earth retaining structure (for crushed stone grade A), **the degree of compaction** the quality of compacted soil is controlled by K30 value. Test cross sections shall be provided at an interval of every 30m for performance rank I. Minimum one test in each section and in approach block.

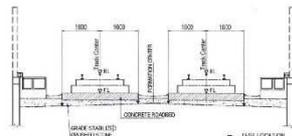


Fig 17. Test Location for K30 Value

6.5.4 Testing Location for Compaction Density for Back Fill Materials:

In backfill for earth retaining structure and approach block of abutment, relative compaction tests shall be carried out for every layer (0.3m). The testing shall be carried out at every 30m cross section for performance rank I. Minimum one test section in each section and in approach block.

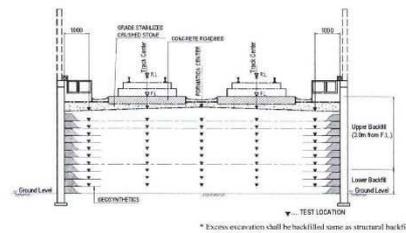


Fig 18. Test Location for Compaction Density Test

6.5.5 Criteria for backfill.

The degree of compaction for backfill for earth retaining structure shall be based on the base values and the quality control method as mentioned below in Table-11. In case the upper backfill for earth retaining structure is banked, the compaction control shall be by average and lower limit values of K30 and the ratio of density for compaction. In case lower backfill for earth retaining structure, the compaction control shall be by average value and lower limit of the ratio of density for compaction.

The degree of compaction shall be as detailed below in Table 11.

mesh of the approach block without using internal concrete formwork. The main part of the reinforced concrete wall shall not be constructed before the construction of the approach block behind. In the same way, the RC parapet wall shall not be constructed before the construction of the approach block behind. This procedure is to ensure firm connection between the reinforced concrete wall and the approach block and to avoid uncontrolled displacements of the reinforced concrete wall that may take place if the RC wall is constructed prior to the construction of the approach block.

[About the timing of assembling of the steel reinforcing bars for the RC abutment wall]

It is the standard practice to assemble the cage of steel reinforcing bars for the RC abutment structure after the construction of the approach block so that, before the start of rusting of the steel reinforcing bars, fresh concrete can be cast-in-place to complete the RC abutment structure that is firmly connected to all geosynthetic layers reinforcing the approach block.

Although it is not preferable, depending on construction conditions at the site, if the foundation structure for the RC abutment structure is constructed then the cage of steel reinforcement for the RC abutment structure is assembled before the start of the construction of the approach block, so well in advance of the casting-in-place of fresh concrete, steel reinforcing bars shall be protected from rusting by a relevant means. This protection work shall be started immediately after the completion of the assembling of the steel reinforcing bars and continued until the time of concrete casting.

The thickness of the Cement Mixed Stabilized Crushed Stone mix layer that is to be compacted one time shall ~~be not~~ not be more than 150mm. However, the testing of approach block layer shall be done for every 300mm layer. In situ field dry density shall satisfy 95% or more, than the max dry density by Modified Proctor.

Approach block backfill for ~~earth-retaining structure~~ GRS Bridge Abutment shall be carefully compacted, as the connection of the ~~structure and the backfill for earth-retaining structure~~ RC abutment structure that supports the bridge girder with the approach block has a severe influence on the track.

Curing of ~~ement-block compacted~~ cement-mixed soil layers shall be ensured using water sprinkling until the next layer is laid.

Required tests like unconfined compressive strength test shall be carried out as per ITP for Cement Mixed Stabilized crushed Stone mix.

Prior to the start of the construction of Abutment/RCC wall construction, 16mm dia anchor reinforcement bars with vertical spacing at 300mm and horizontal spacing at 250mm shall be connected with the wire mesh provided along with approach block, as shown in fig. 20 above.

The surface of the final finished top layer shall be sealed by spraying bitumen emulsion about 1.0 to 2.0 liter per m2 conforming to grade SS-1 (IS: 8887-2017).

6.7 Degree of Compaction and Test Method for Approach Block

Field tests to evaluate the Degree of compaction of the approach block and ~~compaction test method~~ plate loading tests for construction control shall be carried out as detailed below in the table 12.

Table-12 Degree of Compaction and ~~Test Method~~ Plate Loading Tests for Approach Block

Backfill for earth retaining structure part	Degree of Compaction and K30 Value	Compaction Management method
Approach Block	Relative compaction is 95% or more by Modified Proctor and K30 value is 150 MN/m3 or more	Same as performance Rank 1 mentioned in Table -11 for upper backfill.

7.0 CONSTRUCTION OF ABUTMENT WALL & RC FACING WALL: RC FACING FOR GRS RETAINING WALL AND RC ABUTMENT STRUCTURE FOR GRS BRIDGE ABUTMENT:

After completion of laying of Back fill and Cement Mixed Stabilized crushed Stone mix to the required height as per drawing. Observation of deformation before casting of RC facing shall be complying. After the construction of the approach block for the GRS bridge abutment and the reinforced backfill for the GRS retaining wall to the required height as per drawing, before casting-in-place fresh concrete to construct the RC abutment structure and RC facing, the end of sufficient deformation and settlement of the approach fill and the geosynthetic-reinforced backfill together with the settlement of the supporting ground shall be confirmed by continuous observation.

Then, the construction of RC abutment structure and RC facing. Then, the construction of RC abutment structure and RC facing shall commence the following sequence.

- a) Temporary scaffolding assembly work
- b) Reinforcing steel rod assembly work
- c) Form Work
- d) Concrete casting work

In the following, the construction method of RC facing for the GRS retaining wall are commented. As the construction method of RC abutment structure for the GRS bridge abutment is basically the same as the above, these comments are also relevant to the construction of the RC abutment structure for the GRS bridge abutment.

7.1 Temporary scaffolding assembly work

Temporary scaffolding assembly is to facilitate fixing of RC wall form work. The scaffolding, pipe scaffolding, or prefabricated scaffolding shall be as per drawing.

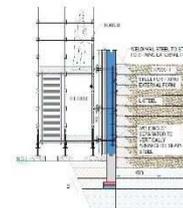


Fig. 20 21. Temporary scaffolding assembly work (This figure should be modified to Fig. A-a) shown below)

In Fig. 21, the top level of the embedded portion of the full-height (FHR) RC facing is too high. As this embedded portion is constructed before the construction of the reinforced backfill, by this configuration shown in Fig. 21, the first soil layer of the reinforced backfill is NOT connected to the FHR facing.

However, the bottom part of the FRH facing should be firmly connected to the bottom soil layer of the reinforced backfill by casting-in-place fresh concrete into a space between the front face of the first soil layer and the back face of the FHR RC facing not covered with an internal concrete formwork (in the same way as the higher portion of the FHR RC facing).

So, the top level of the embedded portion of the FHR RC facing should be made lower by 30 cm to become the same as the bottom level of the first soil layer of the reinforced backfill as shown in Fig. A-a) below. Then, the bottom level of the scaffold should also be made lower by 30 cm accordingly, as shown in Fig. A-a). Figs. A-b) and A-c), which were produced from the approved drawing, show the structure of the bottom portion of FHR RC facing.

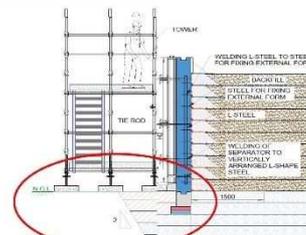


Fig. A-a)

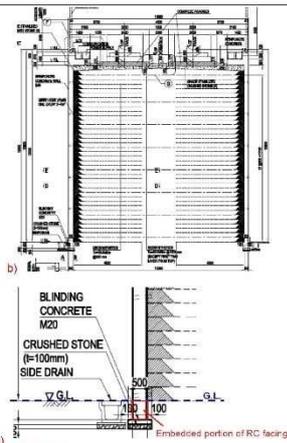


Fig. A. a) Modified figure of Fig. 21;
 b) a typical cross-section of the embankment retained by a pair of GRS RWs shown in the approved drawing; and
 c) details of the structure at the bottom portion of FHR RC facing (note: a blue broken line and a red square have been added to the original drawing).

7.2 Reinforcing steel work.

Tying of Reinforcement and binding for RC wall shall be as per BBS and approved drawing. Embedded items like pipe for weep holes/ drain holes etc. shall be ensured during reinforcement tying as per drawing. Cover blocks shall be provided on the outside having concrete grade equal to or higher than the RC wall concrete grade.

The L hooks provided in geo synthetic layers shall be welded with the RC wall reinforcement as per drawing.



Photo 5. Reinforcing Bar

Photo 6. Drain Pipe

7.3 Formwork Arrangement:

Fixing of formwork shall be as per drawing. Required tie rod with anchor cone shall be provided to ensure the alignment and rigidity during concrete pouring and compaction. Form work at the backside of reinforced concrete wall (backfill side) shall not be used.

Required protection for drainpipes and weep holes shall be ensured while fixing the shutter for concreting works.

Necessary foam sheets / putty shall be provided in the form work/joints to ensure leak free joints to prevent slurry leakages through joints.

Shutter oil shall be applied to the form work prior to fixing of formwork.



Photo 7. Formwork

7.4 Casting of RC Wall:

Concrete mix shall be produced from an automatic batching plant as per the approved mix design. The grade of concrete shall be as per drawing. Pre-pour inspection shall be carried out with RFI and clearance shall be taken prior to commence concrete.

Concrete shall be poured directly or using boom placer / static pump into the RC wall form works. Care shall be taken while pouring and compaction to ensure that the embedded items inside the RC wall formwork are not disturbed, dislocated, or damaged.

The compaction of concrete shall be continued until the air bubble stops coming out and the cement slurry starts coming out from the concrete. The compaction shall be stopped when the cement slurry starts coming out through the concrete surface.

Peptalk shall be carried out to the team prior to start every concrete to ensure defect free concrete surface. Water curing of concrete top surface (exposed surface) shall be commenced as soon as the concrete is initially set. Alternatively curing compound shall be applied.

7.5 De-shuttering.

After 18 to 24 hours after concrete, the form work shall be removed. The concrete surface shall be inspected jointly for post-pour. Defects, if any observed shall be recorded in the post pour inspection sheet and attended as per approved concrete repair method statement.

7.6 Concrete Curing

Immediately after the De shuttering, curing compound shall be applied to the outer face of RC Wall. Alternatively curing shall be done by covering with hessian cloth & sprinkling using water continuously for 15 days.

7.7 Expansion Joint & Contraction Joint:

The longitudinal length of a reinforced concrete wall between expansion joints shall not be more than 20m, and it can be shortened depending on the site conditions and as per the drawings.

Contraction Joints (V-shaped concrete cuts) shall be done using concrete cutter on the RC wall surface at an interval as specified in the drawings in case the length of wall is greater than 20m.

The inspection and testing of RC wall construction shall be carried out as per ITP, and the records for the same shall be maintained.

8.0 Outer Drainage Works:

Construction of drainage systems like weep holes, geo-composite drains, side drains, catch water drain etc., shall be done as per drawing after completion of RC wall construction. The size of perforated concrete pipes for side drains shall be as per drawing. The level of drain works shall be as per drawing to ensure proper drainage and to prevent accumulation of water inside the earthworks area.

10. Casting of Noise Barrier & Cable Duct Adjusting Concrete:

Noise barrier and cable duct adjusting concrete shall be done as per drawing. The method statement and ITP for noise barrier adjusting concrete and the erection of Noise barrier and cable duct shall be as per approved Method statement. Please refer LTC/MAHSR/Pkg-C4/QMS/2023/9039, SRR-016186 & SRR-017529.

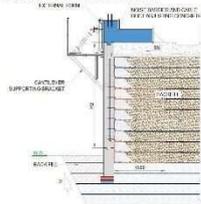


Fig. 20 22.

(note: the embedded portion of the RC facing shown in this figure should be modified as shown in Fig. A-a, presented immediately below Fig. 21).

The structure of the top portion of the FHR RC facing shown in Fig. 22 should be modified to the one presented in Fig. B (shown below). In Fig. B, the FHR RC facing is constructed as one unit up to the crest of the extended portion so that a construction joint is not created between the extended portion and the main portion of FHR RC facing. This construction joint, if produced, reduces the stability of the extended portion of the RC facing as the extended portion is not supported by the reinforced backfill.

Figs. C and D are from the approved drawing. As shown in Figs. B, C and D, the vertical steel reinforcement members, denoted as RM, are arranged throughout from the bottom of the RC facing to the crest of the extended portion of the RC facing. As shown in Fig. B, the base concrete of the noise barrier should be firmly anchored in the extended portion of the RC facing by using anchor steel members (denoted as AM in Fig. B). In this way, the noise barrier becomes stable sufficiently by taking advantage of very high stability of the FHR RC facing.

In Annex 2 (at the end of this document), it is shown that, after the main portion of the RC facing is constructed at stage 6, the concrete block consisting of the foundation for the noise barrier and the cable duct adjusting concrete is constructed at a later stage, stage 7. However, when following

this procedure, a construction joint is created between the extended portion and the main portion of RC facing. Moreover, a scaffold and the support for external concrete formwork arranged outside the wall face becomes necessary.

For construction convenience at a lower cost and also for a high structural integrity between the main portion and the extended portion of the FHR RC facing, it is necessary to construct these two portions of RC facing at one time so that a construction joint is NOT produced between these two portions. A set of illustration presented in Fig. E shows a modified construction procedure that does not use the scaffold and related members to support the external concrete formwork to construct the extended portion of the FHR RC facing (shown in Figs. 22 and B). The construction procedure shown in Fig. E follows the approved drawing presented in Figs. C and D.

The duct base concrete shown in Fig. E is not a structural component. A simple measure, such as a small protrusion at the bottom plane of the duct base concrete together with a steel member connecting the duct concrete base and the base concrete for noise barrier, is enough for its stability.

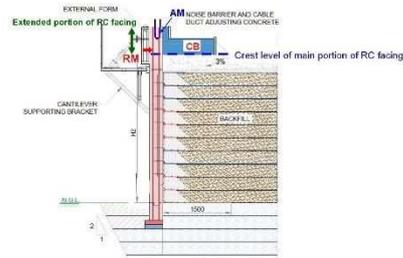


Fig. B. Modified structure of the top portion of the FHR RC facing (note: the crest level of the embedded portion of the FHR facing is made the same as the bottom of the first soil layer of the reinforced backfill, which is set to be the same as N.G.L. in this figure).

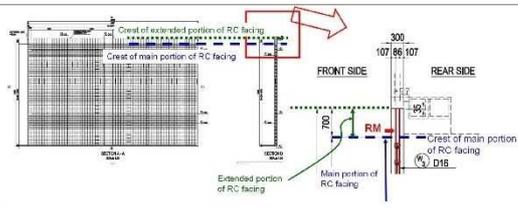


Fig. C Arrangement of steel reinforcement members (from the approved drawing)

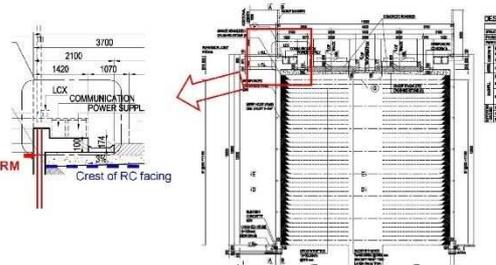


Fig. D (from the approved drawing) (note: coloured lines and notes have been added to the approved drawing).

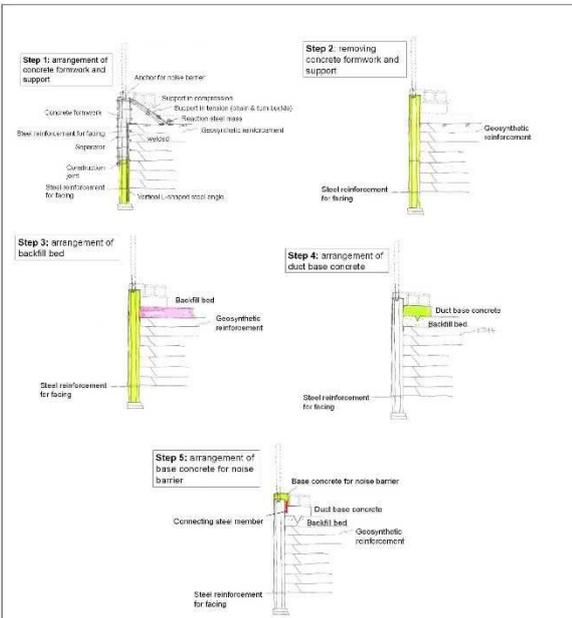


Fig. E. A modified construction procedure of FHR facing.

11. QUALITY ASSURANCE & QUALITY CONTROL:

- All testing and inspections shall be carried out as per approved ITP.
- Curing shall be ensured as per specification.
- Records of testing and inspections shall be ensured as per approved ITP.

In this document, the construction procedure of the GRS RW with FHR RC facing having the foundation of a mast, as shown in Fig. F, is not explained. It is necessary to prepare it referring to the comments presented in this document.

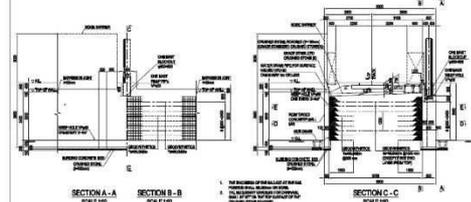


Fig. F. Section of GRS RW with FHR facing having the foundation for a mast (from the approved drawing)

ANNEXURE-2

TYPICAL CONSTRUCTION SEQUENCE DRAWING

STAGE-3:

1. CAST REINFORCED CONCRETE (RCC) FOR THE FHR RC FACING.
2. PLACE THE REINFORCING BARS AS PER SPECIFICATION AND APPROVED DRAWING.
3. PLACE TEMPORARY HOLDING JUMPS (BRIDGE BOLTS) TO PREVENT SPALLING.
4. PLACE TEMPORARY HOLDING JUMPS (BRIDGE BOLTS) TO PREVENT SPALLING.
5. COVER THE LAYERS AS PER REQUIREMENTS AND APPROVED DRAWING.
6. COVER THE LAYERS AS PER REQUIREMENTS AND APPROVED DRAWING.

DO NOT USE FOR DETAILS, SHALL BE AS PER APPROVED DRAWING.

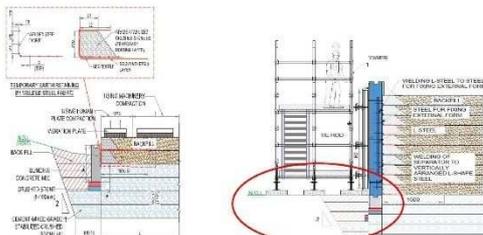


Fig. A-a) (ditto)

As commented related to Fig. 21, the crest level of the embedded portion of the FHR RC facing should be lowered to become the same as the bottom level of the first layer of the reinforced backfill as shown in Fig. A-B).

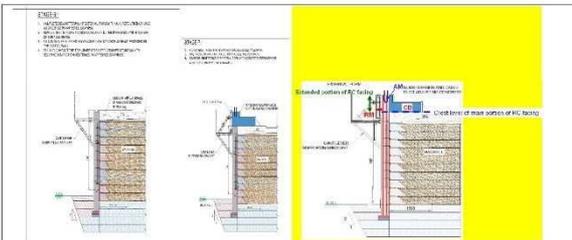


Fig. B (ditto)

In these two figures on the left side (shown in the table in ANNEXURE-2 of the original document), the main portion of FHR RC facing is constructed at stage 6, while, subsequently, the foundation for the noise barrier and cable duct adjusting concrete are constructed at stage 7 separately and later. However, as commented related to Fig. 22, and as shown in Fig. B (shown at the right side above), these two portions should be constructed one time to ensure their integrity and for construction convenience.

