Manual for the design and construction of RRR Geosynthetic-Reinforced Soil structures

RRR ASSOCIATION OF RRR CONSTRUCTION SYSTEM

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Preface

About forty years ago, at the University of Tokyo and then at the Japan Railway Technical Research Institute, the research on the methods to design and construct geosynthetic-reinforced soil (GRS) structure that can be used for important permanent structures, such as high speed railways, started. A number of consulting companies and construction companies joined the research programs. In the 1980's, GRS retaining wall (RW) having lightly steel-reinforced full-height rigid (FHR) facing was developed. After the geosynthetic-reinforced backfill and subsoil has deformed sufficiently by the deadweight of the reinforced backfill, the FHR facing is constructed by casting-in-place fresh concrete in such that the FHR facing is eventually firmly connected to the geosynthetic reinforcement layers. The FHR facing enhances highly stable integrated behaviour of GRS structure, in particular against strong seismic loads, heavy rainfalls and floods. The FHR facing functions also as foundations for several types of facilities including noise barriers, guardrails, electric-supply poles etc. In the early 1990's, GRS Bridge Abutment supporting one end of a simple girder at the top of the FHR facing was developed. In the early 2000's, GRS Integral Bridge was developed, which integrates both ends of a continuous girder to the top of the FHR facings of a pair of GRS RWs. For the last about thirty-five years mainly in Japan and also outside Japan, a great number of GRS structures of these types have been successfully constructed for railways, including high-speed railways, highways and others. The total wall length of these GRS structures is now becoming about 200 km with no problematic case during and after construction. The FHR facing, its staged construction and the structural integration of the major components (i.e., backfill, geosynthetic reinforcement and RC facing) are the three major breakthrough technologies with these GRS structures.

These GRS structures are now called the RRR GRS structures. RRR stands for *Reinforced-soil Road structures with Rigid facing*. The design and construction technology of RRR GRS structures are managed by Association of RRR Construction System (http://www.rrr-sys.gr.jp/en/). The brochure of the RRR GRS structures can be downloaded from this homepage. This English version of the manual for the design and construction of the RRR GRS structures was prepared by translating the original Japanese version published 2021, except for Appendixes, which include many design examples. The English version of the Appendixes will be published in the near future.

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Chapter 1 General Provisions

1.1 General Provisions

1.1.1 Definitions

The RRR Construction System is a reinforced soil construction technology that uses a full-height rigid facing that has large flexural rigidity and uses a reinforcement (planar or rod-like). The System comprises the following subsystems:

(1) RRR-A Construction Method (Method for constructing geosynthetic-reinforced soil abutments and bridges)

(2) RRR-B Construction Method (Method for constructing geosynthetic-reinforced soil retaining walls having a full-height rigid facing)

(3) RRR-C Construction Method (Method for constructing nail-reinforced cut soil retaining walls having a full-height rigid facing)

(4) RRR-D Construction Method (Method for constructing waterfront disaster-prevention reinforced embankments)

[Commentary]

The RRR Construction System is a reinforced soil construction technology developed by the Railway Technical Research Institute (RTRI) based on cooperative research by RTRI, the University of Tokyo and other institutes. “RRR” stands for “Reinforced-soil Railway/Road Structures with a Rigid Facing”. Under the present circumstances, the RRR Construction System comprises four subsystems: namely, the RRR-A Construction Method (Method for constructing geosynthetic-reinforced soil bridge abutments), the RRR-B Construction Method (Method for constructing geosynthetic-reinforced soil retaining walls having a full-height rigid facing), the RRR-C Construction Method (Method for constructing nail-reinforced cut soil retaining walls having a full-height rigid facing) and the RRR-D Construction Method (Method for constructing waterfront disaster-prevention reinforced embankments).Table 1.1.1-1 gives an overview of these methods.

Table1.1.1-1 Abstract of RRR construction system

Kinds of construction method		Structures		Abbreviation
RRR-A	Abutment & Bridge Construction Method	Geosynthetic-Reinforced Soil Bridge Abutments		①RRR-GRS Bridge Abutments
		Reinforced Soil Integral Bridge	Geosynthetic-Reinforced Soil Integral Bridge	②RRR-GRS Integral Bridge
			Nail Reinforced Soil Integral Bridge	③RRR-NRS Integral Bridge
RRR-B	GRS Retaining Wall Construction Method	Geosynthetic-Reinforced Soil Retaining Walls		④RRR-GRS Retaining Walls
RRR-C	NRS Retaining Wall Construction Method	Nail-Reinforced Soil Retaining Walls		⑤RRR-NRS Retaining Walls
RRR-D	GRS Disaster Prevention Embankment Construction Method	Geosynthetic-Reinforced Soil Structures to Prevent Water-Front Disasters		⑥RRR-GRS Disaster Prevention Embankment
Derivatives	GRS Box Culvert Construction Method	Reinforced Soil Box Culvert		⑦RRR-GRS Integral Box Culvert
	GRS Tunnel Entrance Construction Method	Reinforced Soil Tunnel Entrance		⑧RRR-GRS Tunnel Entrance

GRS :geosynthetic-reinforced soil structure
NRS :nail-reinforced soil structure

(1) RRR-A Construction Method (Method for constructing geosynthetic-reinforced soil abutments and bridges)

The RRR-A Construction Method consists of cement-treated approach blocks made of a geosynthetic-reinforced soil structure using a planar reinforcing material (hereinafter referred to as “Geotextile”) and a steel-reinforced concrete RC facing. It is a highly cost-effective abutment that has superior earthquake-resistance and possesses the following characteristics:

a Since cement-treated well-graded gravelly soil is used to construct the approach blocks, the amount of seismically induced settlement will be reduced significantly.

b Since the RC facing is connected with multiple layers of geotextile that reinforce the cement-improved soil approach blocks, the stability of the facing will improve significantly, and the cross-section of the facing will become slender.

c Since the approach blocks and the embankment are built prior to the RC facing, there will be no problems, such as the concentration of stress at the connections between of the RC facing and the geotextile layers are connected, that will arise due to the deformation of the ground or the embankment.

(2) RRR-B Construction Method (Method for constructing geosynthetic-reinforced soil retaining walls having a full-height rigid facing)

The RRR-B Construction Method is a method for constructing a vertical or near-vertical soil-retaining wall by making use of a full-height wall facing that has large flexural rigidity connected to geotextile layers reinforcing the backfill. The RRR-B Construction Method is a method for constructing a geosynthetic-reinforced soil retaining wall that has the following characteristics:

a This construction method enables the construction of this type of wall to be carried out at a smaller and narrower site than a traditional retaining wall site.

b Since this construction method uses a full-height wall facing with high rigidity, the wall will show high stability and low deformation.

c Since the geotextile layers are arranged in a concentrated manner, there will be a relatively wide variety of soil types that can be used as the backfill for the construction of this type of wall.

Constructing a vertical or near vertical wall by arranging multiple layers of geotextile in the backfill has long been practiced. It has been proven that if a full-height wall facing having high rigidity against bending, compression and shearing is additionally used, the stability of the wall will be significantly improved, and the wall deformation will be significantly reduced. Based on this, this technique has been used in the construction of many railway soil retaining walls. In the recently revised “Design Standard for Soil Structures for Railway Structures” and “Design Standard for Earth Retaining Structures for Railway Structures”, this method is presented as the standard construction method.

Further, in March, 1990, we obtained a “General Civil Engineering and Technical Examination Certificate” (No. 0505) from the Japan Institute of Country-ology and Engineering again for the RRR-B Construction Method to make sure that the Method would be applied to the construction of road retaining walls. Currently, the Method is used widely also for the construction of road retaining walls.

(3) RRR-C Construction Method (Method for constructing reinforced-cut soil retaining walls having a full-height rigid facing)

The RRR-C Construction Method is a construction method for making the slope of the natural ground (cut soil) steep or near vertical by using a full-height wall facing and a reinforcing material that has large flexural rigidity. The RRR-C Construction Method has the following characteristics, among others:

a Since the Method uses a full-height wall facing with high rigidity, it makes it possible to keep the slope deformation after construction low and stability high.

b Since the Method makes it possible to create a new flat space by cutting the existing slope, the land can be utilized effectively.

(4) RRR-D Construction Method (Method for constructing waterfront disaster-prevention reinforced embankments)

The RRR-D Construction Method is a method for constructing a wall or a slope having an integral slope work or a wall facing works that has flexural rigidity to prevent natural disasters such as tsunami, waves and floods. The backfill is reinforced with multiple layers of geotextile that are firmly connected to a wall facing or a slope work to form a water-front reinforced soil structure that will show tenacious resistance against scouring of the ground and collapse/outflow and erosion of the backfill due to floods, waves and tsunami overflow.

As stated above, the RRR Construction System comprises four construction methods. This Manual deals only with the RRR-B Construction Method.
Further, the RRR Construction System is protected by many construction method patents. Only the member companies of the RRR Construction Method Association which has been granted a license for any of such patent can practice it.

Those construction contractors desiring to carry out the RRR-B Construction Method will be allowed to do so if they join the Association of RRR Construction System as a temporary member for one construction project alone under one contract. (For details, please contact the Secretariat of the RRR Construction Method Association.)

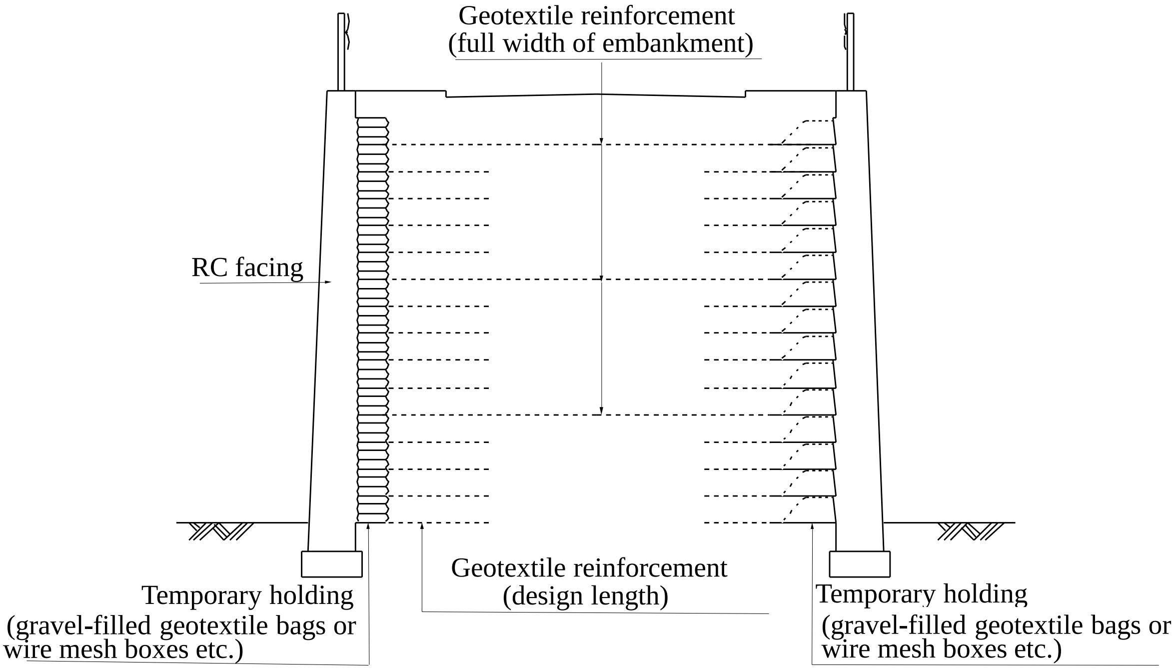


Figure 1.1.1-1 (a) Standard drawing of RRR-B structure with double-sided reinforced soil retaining walls

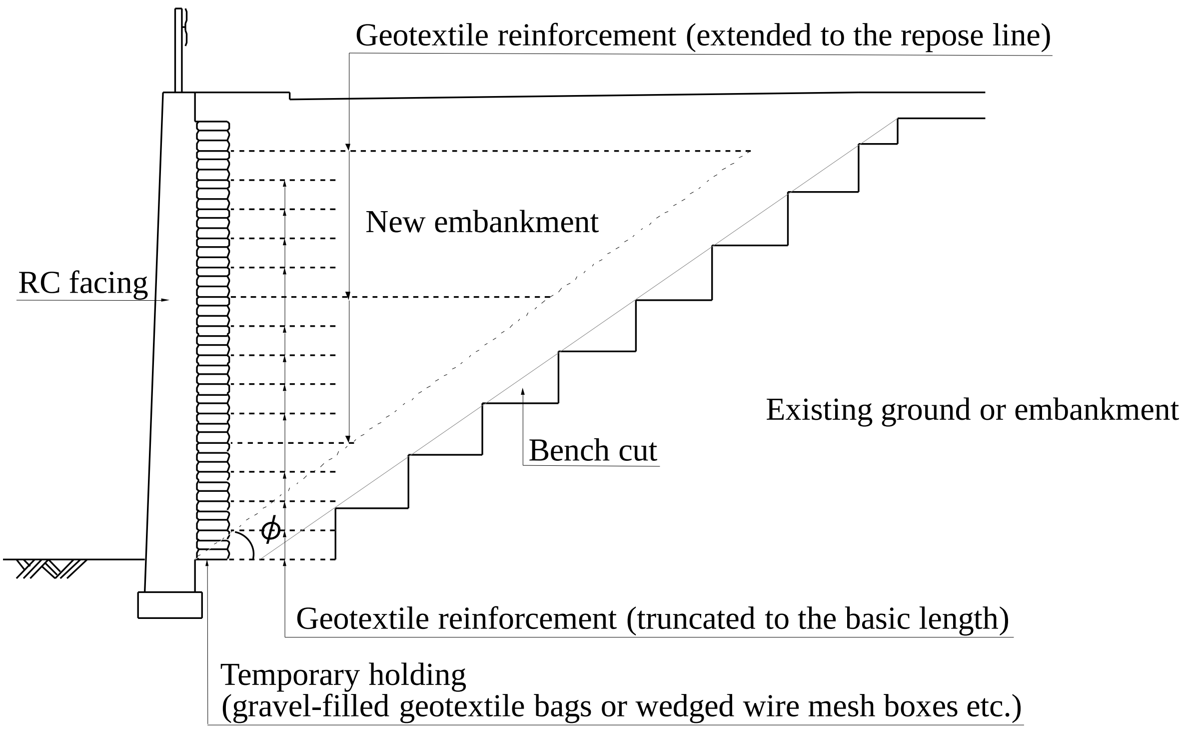


Figure 1.1.1-1 (b) Standard drawing of RRR-B structure widening the embankment

1.1.2 Applicable Scope

This Manual gives an overview of requirements for design and installation on the premise that the RRR-B Construction Method will be applied to the construction of railway retaining walls. Accordingly, for any cases where the RRR-B Construction Method is applied to any applications other than railway retaining walls or any matters that are not stipulated in this Manual, refer to various relevant standards and specifications.

[Commentary]

The RRR-B Construction Method is a method for constructing retaining walls that show high structural stability and low-level deformation properties. It is the construction method for geosynthetic-reinforced soil retaining walls, which has been applied on a full scale for the first time to railway retaining walls including those that are subject to considerably severe restrictive conditions. Because of its high performance, this Method is now used widely for road retaining walls as well.

This Manual gives a presentation of the case where the Method is applied to railway retaining walls on the basis of actual results obtained with railways. Further, the various standards and specifications to which reference should be made for any matters that are not stipulated in this Manual are listed below.

Furthermore, it is possible to apply this Construction Method to high retaining walls exceeding 10 m in height if the stability of the entire structure is secured. However, the height of retaining walls that should be built on a standard basis by the method described in this Manual shall be 10 m or so or lower. If this Construction Method is to be applied to retaining walls higher than that, an adequate investigation shall be made by expert engineers.

1) Design Standard for Railway Structures and Commentary - Earth Structures (January, 2007; 2013 revised) (hereinafter referred to as “Design Standard for Earth Structures”)
2) Design Standard for Railway Structures and Commentary – Earth Retaining Structures (January, 2012) (hereinafter referred to as “Design Standard for Earth Retaining Structures”)
3) Design Standard for Railway Structures and Commentary – Aseismic Design (September, 2012) (hereinafter referred to as “Aseismic Design Standard”)
4) Design Standard for Railway Structures and Commentary – Concrete Structures (April, 2004) (hereinafter referred to as “Design Standard for Concrete Structures”)
5) Design Standard for Railway Structures and Commentary – Foundation Structures (January, 2012) (hereinafter referred to as “Design Standard for Foundation Structures”)
6) Design Standard for Railway Structures and Commentary – Cut-and-cover Tunnels (March, 2001) (hereinafter referred to as “Design Standard for Cut-and-cover Tunnels”)
7) Design Standard for Railway Structures and Commentary – Steel and Composite Structures (July, 2009) (hereinafter referred to as “Design Standard for Steel Structures”)
8) Design Standard for Railway Structures and Commentary – Guide for Examination of Performance of Concrete Structures (September, 2010)
9) RRR Construction Method Association: RRR-B Construction Method Materials Manual (August, 2008) (hereinafter referred to as “Materials Manual”)

The following are the standards and specifications to which you should conform in applying this construction method to road retaining walls and other general embankments:
1) Japan Institute of Country-ology and Engineering: “General Civil Engineering Works Method and Technology Examination Certification – RRR (Reinforced soil Retaining Walls Having Full-height Rigid Facing)” (March, 2012)
2) Japan Highway Public Corporation: “Road Bridge Specifications and Exposition: IV Bottom Section Structures” (March, 2012)
3) Japan Highway Public Corporation: “Road Civil Engineering – Guide for Retaining Wall Construction” (July, 2012)
4) Japan Highway Public Corporation: “Road Civil Engineering – Guide for Cut Construction and Slope Stabilization Construction” (June, 2009)
5) Japan Highway Public Corporation: “Road Civil Engineering – Guide for Embankment Construction” (April, 2010)

6) NEXCO: Design Procedures Series 1, Civil Engineering Works (July, 2013)
7) NEXCO: Design Procedures Series 2, Retaining Walls and Culverts (July, 2013)
8) NEXCO: Design Procedures Series 2, Bridge Construction (July, 2013)
9) Architectural Institute of Japan: "Guideline for Building Foundation Structure and Exposition (October, 2001)
10) Public Works Research Center: "Manual for the Design and Installation of Reinforced Soil Using Geotextiles, and Exposition (2^{nd} Revision)" (December, 2013)

Further, if any of the above standards and specifications are revised, the latest edition shall be given precedence.

1.1.3 Applicable Scope

The definitions of main terms relating to geosynthetic-reinforced soil retaining walls, including those constructed by the RRR-B Construction Method, are given below. Further, for the terms relating to performance verification by detailed examination, refer to relevant "Design Standards for Railway Structures".

(1) "Embankment Reinforced soil Retaining Wall": A reinforced embankment structure that is built at a near-vertical or vertical wall face stabilizing the embankment by means of geotextile or a steel reinforcing material and cast-in-place concrete or pre-cast panel wall facings.

(2) "Geotextile": A sheet of a synthetic polymer material that is arranged in the backfill with an aim of the reinforcement of backfill, drainage and the control of soil layer thickness at the time of rolling compaction.

(3) "Full-Height Wall Facing": Full-height nonreinforced or reinforced concrete wall facing that will improve the stability and reduce deformation of the embankment because of its flexural rigidity.

(4) "Reinforced Embankment": An embankment that has stability improved by means of geotextile layers.

(5) "RRR-B Construction Method": The RRR-B Construction Method is a method for constructing retaining wall having near-vertical or vertical wall face by making use of a full-height wall facing that has rigidity against flexure, compression and shear and geotextile layers.

(6) "Reinforced soil Retaining Wall Having Full-height Rigid Facing": A retaining wall having full-height rigid facing that comprises geotextile layers and a cast-in-place concrete wall facing, among other things, constructed by the RRR-B Construction Method.

(7) "Embankment Reinforcement Material": A geotextile that is arranged for the primary

purpose of reinforcing the backfill.

(8) "Upper Embankment Section": The section of a railway embankment that is up to 3 meters in depth from the installation base surface, excluding the subgrade.

(9) "Lower Embankment Section": The section of an embankment that is below the upper embankment section.

(10) "Retained Backfill": An embankment that is built by adequately compacting a soil material in back of a reinforced-soil retaining wall.

(11) "Retained Natural Ground": The natural ground that lies mainly behind a reinforced-cut soil retaining wall.

(12) "Retained Ground": The ground that is behind a soil retaining wall. It is a generic term referring to retained natural ground and retained backfill.

(13) "Reinforced Area": The area in which geotextile layers are arranged.

(14) "Temporary Holding at Wall Face": A material that will ensure the stability of the geotextile-reinforced backfill during the period of construction work until the RC wall facing is installed and, after the RC wall facing is completed, will play a role as a buffer material between the RC wall facing and the geotextile-reinforced backfill and function as a drainage layer.

(15) "Reinforced Soil": A generic term referring to any section of reinforced soil of a reinforced-soil structure that is reinforced with geotextile layers and the RC wall facing.

(16) "Earth Structure": A generic term referring to structures built by using soil etc. as composition materials and various structures in contact with these. If a structure is composed primarily of an embankment, it is called an embankment structure in some cases.

(17) "Reinforced Soil Structure": A generic term referring to reinforced-backfill retaining walls, reinforced-cut soil retaining walls, and reinforced soil bridge abutments.

(18) "Earth Pressure-Resisting Structure": A generic term referring to earth pressure-resisting retaining walls, earth pressure-resisting bridge abutments, box culverts and similar structures in contact with them.

(19) "Earth Retaining Structurers": A generic term referring to earth pressure-resisting structures (excluding box culverts) and reinforced soil structures.

(20) "Two-part Wedge Method": A technique of numerical stability analysis for determining on a trial basis the earth pressure that acts on the back of a wall structure from a static equilibrium between two lumps of soil after defining two sliding planes having different angles in the reinforced area and the non-reinforced area behind it in a reinforced soil structure.

Fig. 1.1.3-1 is shown to make an explanation of the component elements of the RRR-B Construction Method out of the terms defined above.

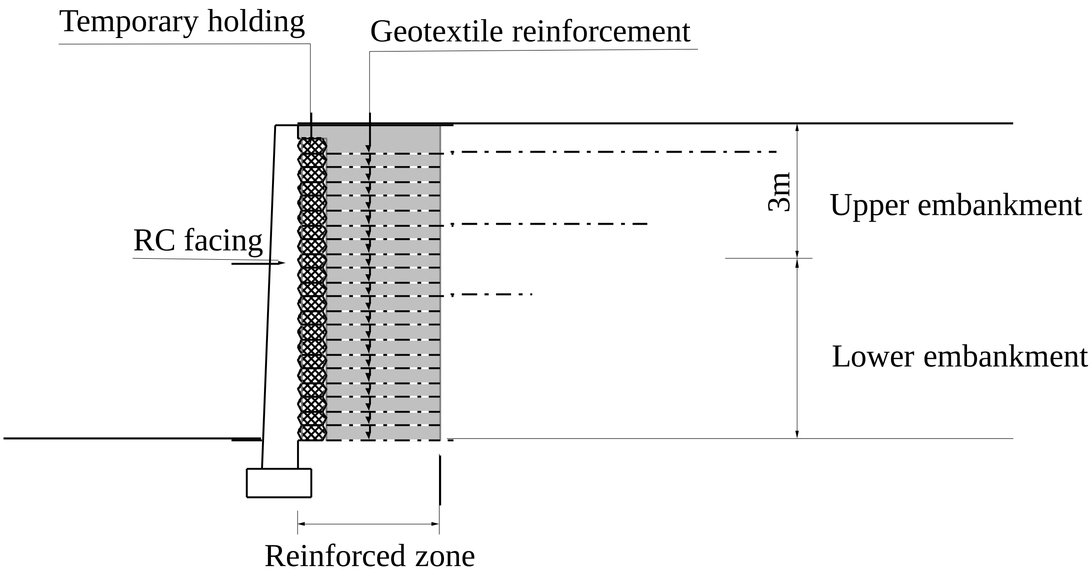


Figure 1.1.3-1 Components of RRR-B structure (GRS RW)

1.2 Investigation

1.2.1 Investigation - General

Before performing planning, design and construction under the RRR-B Construction Method, it is required to make an adequate investigation into the geographic features, geological features, ground water, environmental conditions and other necessary matters.

The items, contents and method of investigation should be determined according to the type, scale, importance, etc. of the construction project.

[Commentary]

The purpose of such investigation is to obtain information necessary for performing specific planning, design and construction and information necessary for maintaining and managing the entire structure after the completion of its construction.

Further, the Design Standard for Earth Retaining Structures shall be applied to the method for such investigation, and it is recommended that reference be made to the Method for Investigation into the Ground and Exposition and Method for Ground Materials Testing and Exposition (first revised edition) published by the Japanese Geotechnical Society.

1.2.2 Type and Contents of Investigation

The investigation shall be conducted into the following matters:

(1) Preliminary investigation
   1) Investigation based on information
   2) Survey
   3) Investigation through discussions with related organizations

(2) Main investigation
   1) Investigation into the embankment foundation ground
   2) Investigation into backfill materials
   3) Investigation into existing embankments (in the case of widened embankments)
   4) Investigation on the aspects of construction works

[Commentary]

The investigation shall be conducted in the following way: first, a preliminary investigation is carried out to identify problems in the construction by gaining information on the general geographical features, geological constitution, soil and other conditions in the vicinity of the site at which construction by the RRR-B Construction Method is to be carried out, and then a formation investigation shall be conducted to make a detailed study.

<u>With regard to (1) above:</u>

Prior to the main investigation, an adequate preliminary investigation shall be carried out so that there will be no need to conduct a reinvestigation.

1) Investigation based on information:

   The purpose of the investigation based on information already available is i) to gain general information on the conditions of the site to find problems before starting to conduct a main investigation and ii) to gather various materials to be used for the subsequent investigation to be made effectively so that problems in the construction project will be identified. Such materials include topographical maps, geological maps, aerial photographs, existing investigation reports and records of construction projects, among other things.

2) Survey:

   The purpose of the survey is to verify the information gained through the investigation based on information already available and confirm other information on the conditions of the site. In conducting this survey, special attention shall be paid to gaining a general idea of the topographical characteristics of the ground, the deformed conditions of the existing structures (subsidence and cracks) and the conditions of ground water (level and spring water).

3) Investigation through discussions with organizations concerned:

With regard to the utilization of land by uses, roads, buried objects, cultural assets, etc., it is necessary to hold careful discussions with the parties managing those properties to make an investigation into the overall shape, dimensions, occupation conditions and future plans.

<u>With regard to (2) above:</u>

Based on the results of the preliminary investigation, a main investigation shall be carried out. Further, prior to the main investigation, a prior investigation is conducted for the purpose of gaining data necessary for carrying out a schematic design in some cases.

1) Investigation into the embankment foundation ground:

In the investigation into the embankment foundation ground, as the need arises, boring is carried out to grasp the general geological features, and standard penetration tests are conducted to investigate the strength of the ground, among other things. A standard investigation depth shall be such that a sufficiently stable stratum that will not pose any problems such as the unstabilization and subsidence of embankments and liquefaction of the ground. As a rule of thumb, such depth in the case of cohesive soil shall be a depth at which the N value is approximately 20 or above; and such depth in the case of sandy soil shall be a depth at which the N value is approximately 30 or above. Further, if the deformation of the ground at the time of an earthquake becomes a problem, the depth of one or so out of several piles shall be such that the foundation surface in aseismic design can be confirmed, as a rule of thumb, such depth in the case of cohesive soil shall be a depth at which the N value is approximately 30 or above; and such depth in the case of sandy soil shall be a depth at which the N value is approximately 50 or above. It is recommended that PS logging be carried out as required.

As a result, for those areas for which a study needs to be made because it is expected that there will be a problem there, sounding, sampling and soil tests shall be carried out. For reference purposes, Table 1.2.2-1 shows selection criteria for sounding that should be used according to the conditions of the ground, and Table 1.2.2-2, the items of soil tests that are necessary for each item of study.

Table 1.2.2-1　Standard selection of sounding

［Design Standard for Earth Retaining Structures, Table 1.2.1］

Ground condition	Kind of sounding	Standard penetration test	Electric static cone penetration testt	Mechanical cone penetration testt	Swedish sounding test	Portable cone penetration test	In situ vane shear test	Simple dynamic cone penetration test
	Standard	JIS A1219	JGS 1435	JIS A1220	JIS A1221	JGS 1431	JGS 1411	JGS 1433
Sandy soil layer having soft soil layer below	gravel sandy layer (large gravel and stone), more than 3m thick, N≧30	○						
	sand　layer (coarse sand with gavel) more than 3m thick, N≧30	◎						
	sandl layer (small gravel) more than 3m thick, N=10~30	◎	○	◎	○			
	sand layer (small gravel) less than 3m thick, N=10~30	◎	○	◎	◎			
Continuous soft clay layer	average N value between 2 to 4	○	◎	◎	◎	○	○	◎
	average N value between 1 to 2		◎	◎	○	◎	◎	◎
	N close to 0 (rammer settles by own weight)		○	○		◎	◎	◎
	N close to 0 (rod settles by own weight)					○	◎	◎

Notes: ◎very effective method, ○effective method

Table 1.2.2-2　Investigation items and laboratory tests
［Design Standard for Earth Retaining Structures, Table 1.2.3］

	Stability	Settlement	Liquefaction	Characteristic values to be provided	Remark※
Test for density of soil particles	◎	◎	○	density of soil particles	JIS A 1202
Test for water content of soils	◎	◎	○	water content of soils	JIS A 1203
Test for liquid limit and plastic limit of soils	◎	◎		consistency index, liquid limit, flow index, plastic limit, plasticity index	JIS A 1205
Test for particle size distribution of soils	◎	◎	◎	maximun grain size, grain size accumulation curve, uniformity coefficient, coefficient of curvature, 50% grain size	JIS A 1204
Test for fine fraction content of soils	○	○	◎	fine fraction content	JGS 0135
Test for minimum and maximum densities of sands			◎	maximum densities, minimum densities	JGS 0161
Test for bulk density of soils			◎	wet density	JGS 0191
Unconfined compression test of soils	◎	◎		unconfined compression strength, modulus of deformation	JIS A 1216
Unconsolidated-undrained(UU) triaxial compression test on soils	◎	◎		coheisionC_u, angle of shear resistance φ_u, voidratio	JGS 0521
Consolidated-drained(CD) triaxial compression test on soils	◎			coheisionC_d, angle of shear resistance φ_d, voidratio	JGS 0524
Cyclic undrained triaxial test on soils	◎		△	liquifaction strength	JGS 0541
Test for one-dimensional consolidation properties of soils using incremental loading		◎		compression index, consolidation yeild stress,coefficient of volume compressibilityprimary consolidation ratio, coefficient of consolidation	JIS A 1217

◎ most frequently used,　○ frequently used,　△ used if necessary
※ JIS is given here as reference. ASTM, BS or other standards may be considered as necessary.

2) Investigation into backfill materials:
An investigation into backfill materials under the RRR-B Construction Method is conducted to determine whether or not the soil planned for use is suitable as a backfill material. Basically, for such investigation, the soil tests listed in Table 1.2.2-3 are conducted. A study for determination as to the suitability of a given soil type as a backfill material is made in accordance with Chapter 5, Materials and Ground, of the Design Standard for Earth Retaining Structures as applied mutatis mutandis).

Table 1.2.2-3 Laboratory tests for backfill materials
［Design Standard for Earth Retaining Structures, Table 1.2.4］

Test items	Test	Test Standard※	Remark
Density of soil particles	Test for density of soil particles	JIS A 1202	
Water content	Test for water content of soils	JIS A 1203	natural state
Grain size distribution	Test for particle size distribution of soils	JIS A 1204	
Liquid limit, Plastic limit	Test for liquid limit and plastic limit of soils	JIS A 1205	
Unit weight	Test for soil density by the sand replacement method	JIS A 1204	natural state
	Test for soil density by the compacted sand replacement method	JGS 1611	
	Tes for soil density using nuclear gauge	JGS 1614	
Compaction curve	Test for soil compaction using a rammer	JIS A 1210	Standard Proctor
Slaking	Slaking test※※		

※ JIS is given here as reference. ASTM, BS or other standards may be considered as necessary.
※※ for rock or fracture rock

3) Investigation into existing embankments:
In the case of adding a new embankment to widen an existing embankment by the RRR-B Construction Method, it is necessary to investigate such existing embankment and the embankment foundation ground underneath it. In the investigations, similarly as in the case of the investigation into the embankment foundation ground as described in 1) above, boring, standard penetration tests, etc. are carried out to check the soil quality, thickness, compaction degree and soil conditions of the embankment foundation ground. As for the investigation into the embankment foundation ground underneath the existing embankment, there is the possibility that a difference has occurred in the strength and deformation properties of the ground due to an increase in compressive strength or anything else that has taken place owing to the effect of the load of the existing embankment. For this reason, it is necessary to make a plan for the investigations, taking the dimensions etc. of the existing embankment into consideration.

4) Investigation on the aspects of construction works:
The investigation on the aspects of construction works is conducted with respect to the following matters so that the construction works may be carried out in accordance with the purpose of the design and safely and securely within the construction period:
i) Topographical and geological features
ii) Weather
iii) Site conditions and land including surface water and ground water conditions
iv) Construction environment
v) Obstacles, buried objects, etc.

1.3 Planning

1.3.1 Basics of Planning

In carrying out the planning and design under the RRR-B Construction Method, it is required to make a study as to the topographical and geological features, related structures, surrounding environment and construction period/construction time on the basis of results of investigations, and it is required to take care to ensure that the structure as a whole will be built rationally in accordance with the type, scale and importance of the construction project.

[Commentary]

In carrying out the planning and design under the RRR-B Construction Method, attention should be paid to the following items, and consideration needs to be given to the relationship with the whole structure in such respects as the connection of the structure with other structures and the rounding of the structure to any planer or intermittent linear sections.

1) Topographical and geological conditions:
   (a) The RRR-B Construction Method provides a certain degree of follow-up properties against the settlement and deformation of the ground that may take place upon the construction of reinforced backfill before the construction of RC wall facing. In the case of thick, soft ground, however, it is necessary to check the overall stability of the ground and to take care to ensure that the integrity of the wall facing, and the embankment will not be impaired.
   (b) In the case of constructing an embankment on a slope or dealing with a landform that is subject to erosion due to topographical features or a river, it is necessary to make a study of the stability of the slope as a whole.
   (c) For a water-collecting landform, such as a swamp, an adequate study shall be made as to drainage, and consideration should be given to the arrangement of drainage lines and the control of water at the time of construction.

2) Adjacent structures:
   (a) In the case where the RRR-B Construction Method is designed for a site adjacent to a bridge abutment, a differential settlement may occur in some cases, and it is necessary to give consideration to reducing such differential settlement as far as possible.
   (b) In a case where it is expected that, in the future, the inside of a reinforced embankment may be excavated or the structure of reinforced soil may be changed by piling, making it impossible to maintain stability, it is necessary to take countermeasures in advance. (Example: Considering objects buried in the ground, a geotextile should not be laid down to 1.5 m from the top of the embankment.)

3) Surrounding environment:

   (a) With the RRR-B Construction Method, it is possible to carry out construction without using large machinery. For this reason, in a case where there are strict restrictions on noise or vibration, the RRR-B Construction Method offers a particular advantage. Furthermore, the Method helps provide an ascetic advantage by using the wall faces made of decorative concrete in some cases.

   (b) In a case where any structure is planned to be installed in a section of a reinforced embankment in the future, it is necessary to give consideration to the spacings in the arrangement of geotextile layers in advance.

4) Construction period/construction time:

   (a) Compared with the period of construction of conventional embankments retained with a cast-in-place concrete retaining wall, the period of construction by the RRR-B Construction Method is generally shorter. Because of this, the Method has excellent applicability to disaster restoration works, among other things.

   (b) The stability of the RRR-B Construction Method depends very much on the level of compaction of the backfill. Accordingly, it is preferable that construction by the Method be carried out avoiding the rainy season or the snow season as far as possible. If such construction is to be carried out in either of these seasons for any unavoidable reasons, it is necessary to give special consideration to such things as using good-quality backfill materials and taking care of their water contents.

1.3.2 Basic Policy for Structure Planning

In structure planning for the RRR-B Construction Method, it is required to have a good understanding of the difference in the mechanism of resistance between the conventional cantilever retaining walls and geosynthetic-reinforced soil retaining walls and give adequate consideration to the construction period. Based on this, in such structure planning, it is required to make decisions so as to ensure that the requirements for the following items will be met and an economic advantage will be gained:

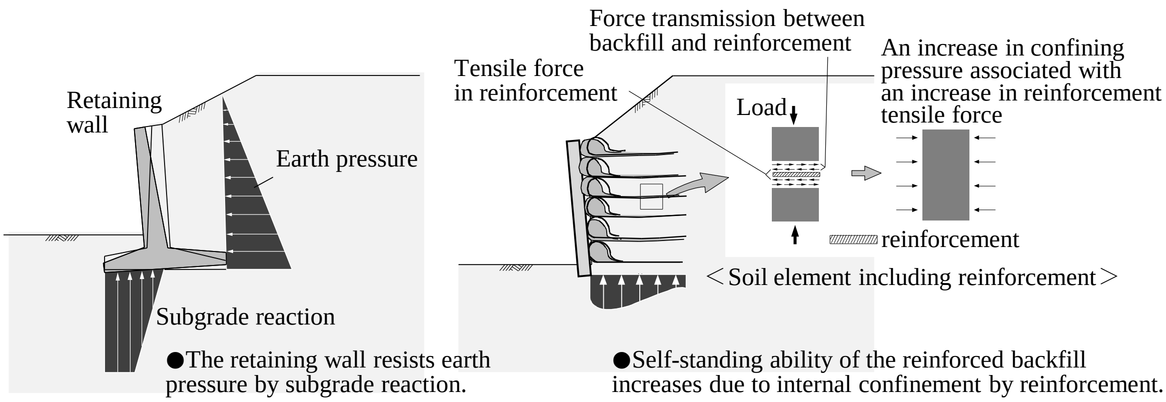
(1) Ground conditions
(2) Connection with the existing embankment
(3) Construction period
(4) Earthquakes, localized heavy rainfalls, etc.
(5) Drainage
(6) Surrounding environment

[Commentary]

Generally, earth pressure-resisting structures provide resistance against earth pressure by the dead weight and the flexural rigidity of the wall facing through the reaction force of the ground that will act on the bottom face of the footing. In this process, an eccentric/inclined load will act on the bottom face of the footing due the dead weight of the wall facing and the earth pressure. For this reason, a great reaction force of the ground will act on the toe of the footing. As a result, in the case of a good-quality ground (for example, sandy soil with an N value of 30 or above; and cohesive soil with an N value of 10 or above), the foundation will be able to support the wall structure directly. However, in the case of a ground that will not have an adequate bearing capacity or a ground that is expected to involve the occurrence of consolidation settlement, it will be necessary to adopt a pile foundation. This in turn will entail higher costs.

In contrast to this, with geosynthetic-reinforced soil retaining walls, a large quantity of a reinforcement (i.e., geotextile) is arranged in the backfill. Accordingly, if the backfill is to be pushed out horizontally in this state, tensile forces will develop in the reinforcement via the frictional force at the interface between the backfill and the reinforcement. As a reaction of this, confining pressure will develop in the backfill. As a consequence, the stability of the reinforced backfill will be enhanced.

Fig. 1.3.2-1 shows the mechanisms of resistance of a conventional earth pressure-resisting cantilever structure and a geosynthetic-reinforced soil retaining wall (Based on 1.3.1 of Design Standard for Earth Retaining Structures). A geosynthetic-reinforced soil retaining wall involve a smaller degree of stress concentration in the ground with smaller deformation. It is important to make a structure plan taking into account these characteristics.



(a) Earth pressure resistant cantilever retaining wall

(b) Reinforced-soil retaining wall

Figure 1.3.2-1 Different resistance mechanisms of earth pressure-resisting cantilever retaining walls and geosynthetic-reinforced soil retaining walls

〔Design Standard for Earth Retaining Structures, Figure 1.3.3〕

With regard to (1) above:

In structure planning for the RRR-B Construction Method, it is essential to investigate mainly the following matters relating to ground conditions:

1) Topographical and geological features
2) Support layer
3) Intermediate layer
4) Ground surface layer
5) Ground water
6) River section
7) Special ground conditions

With regard to (2) above:

In the case of constructing an earth retaining structure by widening an existing embankment by adding an additional embankment to it by the RRR-B Construction Method, it is necessary to pay attention to the following points:

1) Harmful settlement of the existing embankment
2) Sliding along the interface between the old and new embankments

With regard to (3) above:

In the case of the ground of cohesive soil, a problem may arise in the stability of the whole structure including the embankment due to consolidation settlement and lateral displacement, among other things, that may be caused due to an additional load by the dead weight of a newly constructed geosynthetic-reinforced soil retaining wall. In this case, a construction method for dealing with soft ground, such as the consolidation acceleration method, shall be adopted, or it may become necessary to take a longer period for allowing consolidation settlement to occur sufficiently.

Furthermore, it is necessary to investigate the entire process of construction, including avoiding the construction of the embankment in the rainy season, while taking the construction process of adjacent crossing structures, etc. into consideration.

With regard to (4) above:

At the time of the 1995 Great Hanshin-Awaji Earthquake and the 2011 Great East Japan Earthquake, the conventional type retaining walls, bridge piers/abutments and elevated bridges suffered great damage. However, the earth retaining walls that had been constructed by the RRR-B Construction Method in the severely damaged areas were not practically damaged, demonstrating very high seismic stability. Nevertheless, under the special design conditions as shown in Section 2.1, Basics of Design, care needs to be taken about earthquakes.

Further, the earth retaining structures built in water-collecting landforms have suffered much damage from localized heavy rainfalls and rainfalls occurring for an extended period in the past.

Adequate measures need to be taken against rainfalls in the case of constructing earth retaining walls in such landforms.

With regard to (5) above:

In many cases, the collapse of earth retaining walls at the time of localized heavy rainfall occur due to an increase in the pore-water pressure in the retained ground that takes place owing mainly to the concentrated flow-down of rainwater and the seepage of ground water and rainwater. Furthermore, many of the earth retaining structures that suffered deformation were located in water-collecting landforms. This was partly due to seepage water reducing the strength of earth retaining structures.

For this reason, it is necessary to make a drainage work plan so as to ensure that the water that will cause these problems will be processed properly. In particular, it is important to install a proper drainage work system from the perspective of disaster prevention.

With regard to (6) above:

With respect to the surrounding environment, the main basic point is to make an investigate of the following matters:

1) In the case where there are houses, etc. in the vicinity of the site, it is necessary to formulate a structure plan so that there will be no problems such as noises, vibrations, water pollution, and changes in ground and surface water during the construction work and after the structure is put into service.
2) It is necessary to any problems such as deformation and settlement will not arise in the houses, existing structures, etc. in the vicinity of the site during the construction work and after the structure is put into service.
3) If the use of the site land is restricted in any way, there may be some restrictions on the construction machinery that can be used in some cases, depending on the working space available. A structure plan shall be formulated taking account of these points.

Chapter 2 Design

2.1 Basics of Design

2.1.1 Design Policy

Under the RRR-B Construction Method, it is required to study the following design policy according to the purpose of use:

(1) In carrying out design under general design conditions of RRR-B Construction Method, it shall be verified for each performance item by using appropriate detailed examination indices that performance requirements will be met throughout the design durable period (i.e., the design life time).

(2) In carrying out design under special design conditions of the RRR-B Construction Method, appropriate consideration shall be given to their effects, and a study shall be made of safety in construction work as required.

(3) Detailed performance examination to verify satisfactory performance of the structure shall be conducted on conditions that the requirements for the assumptions for the examination, the details of structure, the construction work and the maintenance that are specified in the Design Standard for Earth Retaining Structures are met.

[Commentary]

With regard to (1) above:

Fig. 2.1.1-1 shows the design flow of the RRR-B Construction Method as used under general design conditions other than those shown in (2). In carrying out design under the RRR-B Construction Method, first, it is required to set performance items and detailed examination indices. Next, it is required to calculate design response values by using an analysis model and calculation formula whose validity has already been verified and determine design limit values according to the performance rank. Finally, it is required to conduct a detailed examination to verify satisfactory performance of the structure by using the design response values and the calculation formula. To any matters that are not covered in this Manual, please apply relevant Design Standards for Railway Structures mutatis mutandis.

Further, if required performance is to directly set without regard to the performance rank, it is required to set it appropriately to meet the purposes of use and the design durable period (i.e., the design life time). The design durable period under the RRR-B Construction Method is specified based on the assumption that the conditions for setting the design durable period as shown in relevant Design Standards for Railway Structures applied to the ordinary environment are met as in the case of other earth pressure-resisting structures, earth structures and concrete structures.

With regard to (2) above:

The cases listed below are the special conditions that will necessitate an adequate study to be made in the case of adopting the RRR-B Construction Method. In these cases, it will become necessary to study the improvement of the ground and the work for controlling ground failure including land slide and give consideration to design with respect to excavation work.

(1) A case where a structure is built on a soft, cohesive soil ground, and there is a high possibility that a foundation failure and/or a long-term settlement will occur.
(2) A case where a structure is built on a sandy ground that will involve a possibility of liquefaction at the time of an earthquake.
(3) A case where the slope itself is unstable, typically in a mountainous area, etc.
(4) A case where the surface contour of the retained backfill is complex.
(5) A case where there is a possibility that the inside of a reinforced embankment will be excavated substantially in the future.
(6) A case where a structure is used for a temporary track for a short service period.
(7) A case where the height of a reinforced embankment is high relative to the transversal width.
(8) A case where it is impossible to arrange geotextile layers having a length required for adequate reinforcement in the case of widening the embankment.
(9) Other

<u>With regard to (3) above:</u>

A geosynthetic-reinforced soil retaining wall having full-height rigid facing (hereinafter referred to as “Geosynthetic-Reinforced-soil Retaining Wall (GRS RW)”) that is built by the RRR-B Construction Method is a composite structure combining a geotextile, an embankment, reinforced concrete, etc. For this reason, for the construction of a GRS RW, the construction procedure, construction accuracy and construction management become important. For example, no back framework will be used in building a RC wall facing to ensure that the geotextile layers on the back of the facing will be satisfactorily connected to the facing. One of the characteristics of the RRR-B Construction Method is that construction is carried out on a phased basis in that facing concrete will not be placed before confirming that the deformation of the foundation ground due to the weight of the retained backfill has ceased and come to an end.

Since such construction procedure and construction management will have a significant effect on the performance of GRS RWs constructed by the RRR-B Construction Method in conducting a detailed performance examination, it is important to give appropriate consideration to the assumptions for the detailed examination and to confirm the details of the structure and the conditions of construction and maintenance.

Further, reference shall made to the assumptions of a detailed examination, details of the structure and maintenance that are described below.

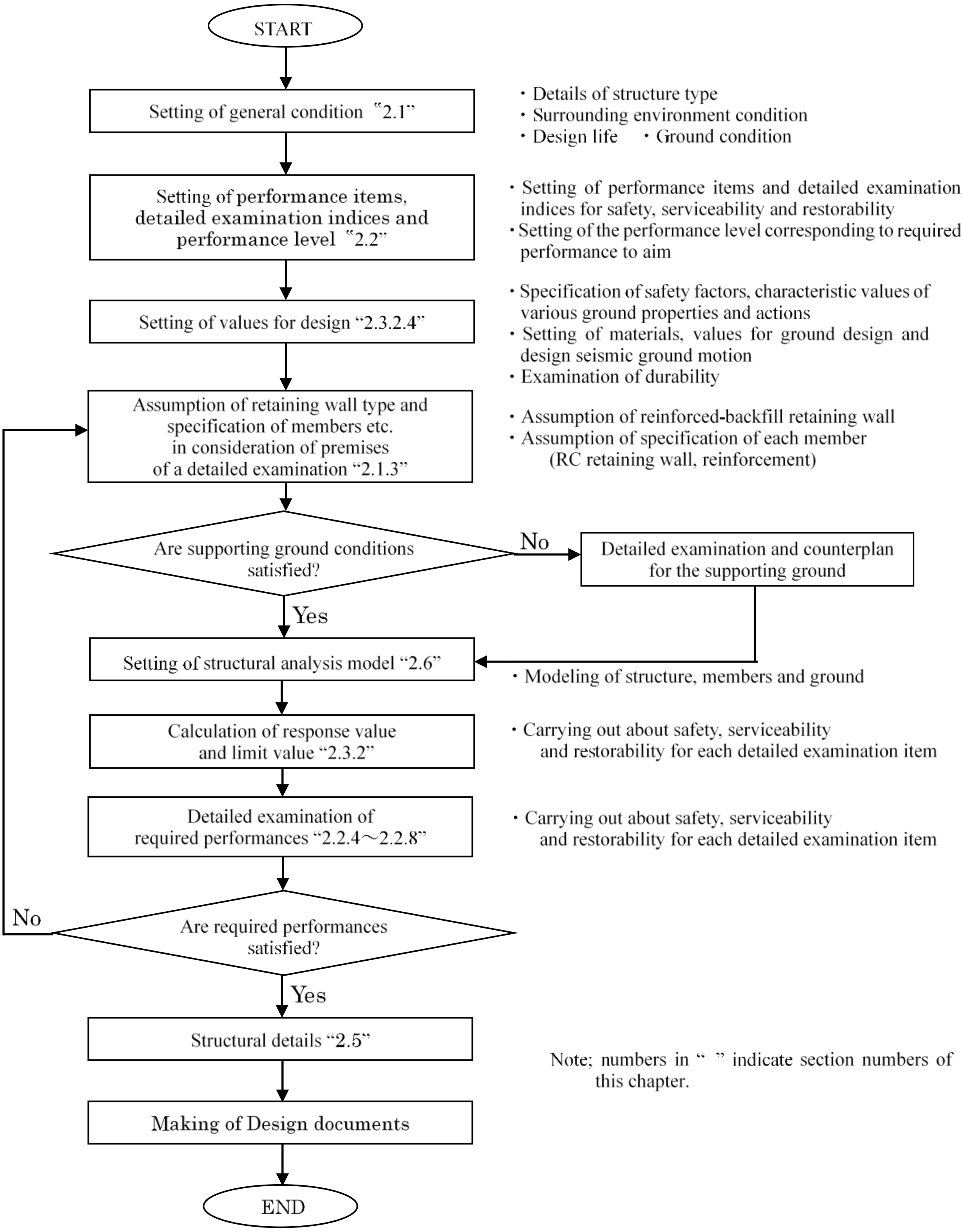


Figure 2.1.1-1　Design flow of RRR-B

2.1.2 Materials Used under the RRR-B Construction Method

The quality and design values of the materials used under the RRR-B Construction Method and the design values of the various numerical figures of the properties of retained backfill shall be in accordance with 2.4, Materials and Ground, and relevant Design Standards for Railway Structures.

[Commentary]

Regarding the materials used under the RRR-B Construction Method, the material for the RC wall facing shall be in accordance with the Design Standard for Concrete Structures pursuant to the Design Standard for Earth Retaining Structures. Furthermore, as to the properties of the backfill material, it shall be in accordance with the Design Standard for Earth Retaining Structures and the Design Standard for Earth Structures.

2.1.3 Assumptions for Detailed Examination Made under the RRR-B Construction Method

A detailed performance examination to verify satisfactory performance of geosynthetic-reinforced soil retaining walls (GRS RWs) built by the RRR-B Construction Method shall be conducted in accordance with 2.5, Details of Structure, and relevant Design Standards for Railway Structures, and the following shall be stipulated appropriately:

(1) The minimum thickness and shape of the RC wall facing
(2) Arrangement and type of the reinforcement

[Commentary]

<u>With regard to (1) above:</u>

The basic principle is that cast-in-place reinforced concrete should be used for the wall facing of a GRS RW built by the RRR-B Construction Method. In this case, the minimum thickness of the facing could be 200 mm. However, but it is also the basic principle that the thickness should be 300 mm or more, taking account of workability in steel reinforcement work and concrete casting work. Moreover, the inclination of the front face of the facing is set to be vertical or 1:0.05 (vertical:horizontal) or so in many cases.

<u>With regard to (2) above:</u>

The arrangement and type of the reinforcement shall be in accordance with 2.4, Materials and Ground, and relevant Design Standards for Railway Structures.

The basic principle is that the arrangement of the geotextile should be as follows:

(1) The minimum laying length of the reinforcement is 1.5 m or 35% of the wall height (height from the front ground surface), whichever is longer (Fig. 2.1.3-1). However, if the retained ground is inclined, the height shall be set to wall height H as shown in Fig. 2.1.3-2.
(2) The reinforcement shall be arranged at a vertical interval of 30 cm according to the finished

thickness of each compacted soil layer. Furthermore, one layer for each 1.5 m of the height shall be arranged back to the line of repose angle drawn from the toe section of the reinforced embankment (back face of the facing) at the angle of repose that is assured to be equal to the internal friction angle Φ.

In any case where it is difficult to arrange the reinforcement on account of any buried objects in the reinforced backfill, an appropriate arrangement shall be determined after making an adequate study (Fig. 2.1.3-3).

(3) The basic principle is that the arrangement of the reinforcement should be made on the assumption that the reinforcement of the same length and quality will be used in the same direction. However, in the case where a large amount of horizontal force will act on the top of the RC wall facing due to the foundation of electric poles or the like, the reinforcement may be arranged in such uneven lengths after making an adequate study of the sectional force occurring in the facing and the stability of the reinforced soil (Fig. 2.1.3-4).

(4) In the case of using a GRS RW for both sides of an embankment, the reinforcement shall be laid at intervals of 1.5 m in the height direction in the full width of embankment (Fig. 2.1.3-5). However, if the width of the embankment is extremely wide, an arrangement shall be made as shown in (5) below.

(5) In the case of widening of embankment, the reinforcement shall be laid back to the bench-cutting end of the existing embankment at intervals of 1.5 m in the height direction (Fig. 2.1.3-6). However, if the bench-cut slope is considerably far apart from the existing embankment, the reinforcement shall be arranged back to the line of repose angle drawn from the toe of the reinforced embankment (Fig. 2.1.3-7). Further, it is preferable that one or two long geotextile layer(s) be laid to ensure the stability of the roadbed at the boundary between the roadbed and the backfill of GRS RW.

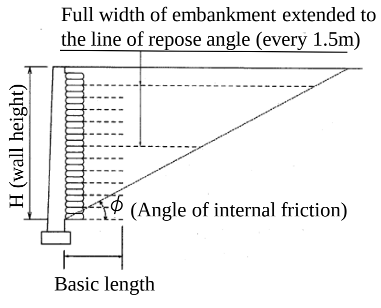


Figure 2.1.3-1 Standard arrangement of geotextile reinforcement

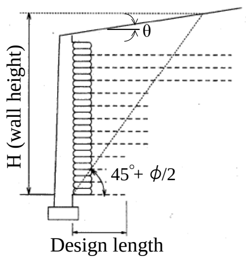


Figure 2.1.3-2 Arrangement when the backfill is back-sloped

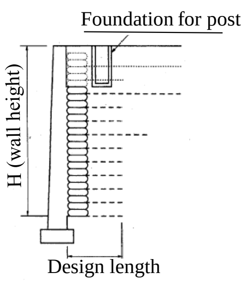


Figure 2.1.3-3 Arrangement when structures are buried in the reinforcement zone

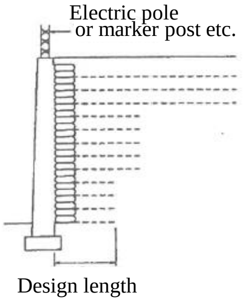


Figure 2.1.3-4 Arrangement of geotextile reinforcement when electric poles are arranged on the top of the facing

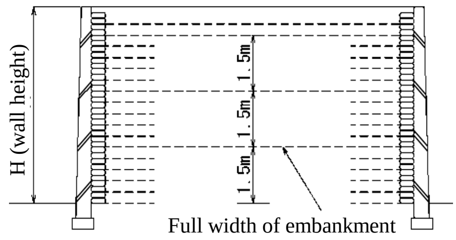


Figure 2.1.3-5 Arrangement when both sides of the embankment are retained by GRS RWs

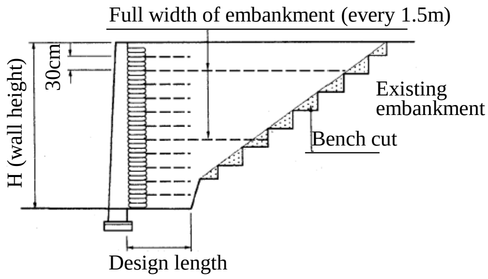


Figure 2.1.3-6 Arrangement when the embankment is widened under ordinary conditions

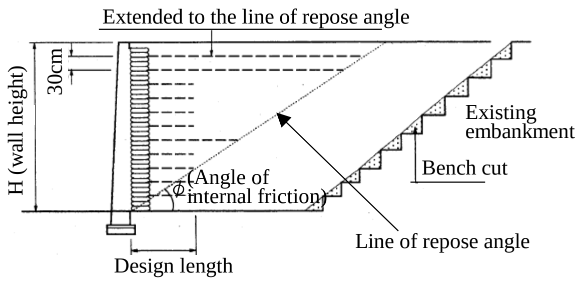


Figure 2.1.3-7 Arrangement when the embankment width is wider than ordinary conditions

2.2 Required Performance and Detailed Examination to verify satisfactory Performance

2.2.1 Required Performance

Requirements for the performance of the geosynthetic-reinforced soil retaining walls (GRS RWs) to be constructed by the RRR-B Construction Method with respect to their safety, usability and restorability shall be set on the basis of the Design Standard for Earth Retaining Structures.

[Commentary]

Requirements shall be set for the performance of the geosynthetic-reinforced soil retaining walls (GRS RWs) to be constructed by the RRR-B Construction Method with respect to their safety, usability and restorability. In this Manual, such performance requirements shall be set by taking into account the transportation volume of each railway line and the track structure. Further, in the Design Standard for Earth Structure, the required performance of the whole earth structures is classified into three levels (Performance Ranks I to III; Table 2.2.1-1). In view of this, in the Design Standard for Earth Retaining Structures, the same performance rank as that of the earth structure on the back of the retaining wall shall in principle be applied to the performance requirements for the GRS RW at the time of setting such requirements.

Table 2.2.1-1 Performance ranks, required performance levels and applications
[Design Standard for Earth Retaining Structures, Table 3.2.2]

	Performance rank I	Performance rank II	Performance rank III
Required performance level	Retaining wall has the following performances: extremely small deformation occurs during normal use but excessive deformation does not occur even in response to both L2 seismic ground motion and very rare torrential rain.	Retaining wall has the following performances: the deforming is permitted to the extent that can be repaired by ordinary maintenance during normal use but catastrophic failure does not occur even in response to both L2 seismic ground motion and very rare torrential rain.	Retaining wall has the following performances: the deforming is permitted during normal use but the failure does not occur in response to both L1 seismic ground motion and rain that occurs several times per year.
Examples of applications※	For example, a retaining wall accompanying an earth structure to support a maintenance-free track	For example, a retaining wall accompanying to an earth structure to support a highly important section of ballasted track	For example, a retaining wall accompanying to an earth structure to support a generalsection of ballasted track.

※ Above examples show just image of the application from the viewpoint of the importance of track structures and sections.

* The example shown in the above table is given from the perspective of the importance of the track structure and the railway length just to give an image of the application.

Table 2.2.1-2 shows the items of the performance requirements for GRS RWs, examples of the selection of the detailed examination indices, and examples of combination with actions.

Table 2.2.1-2 Examples of individual performance items, detailed examination indices and combinations of actions for "GRS RWs"
[Design Standard for Earth Retaining Structures, Table 8.3.5.1]

Required performances	Performance items			Detailed examination indices	Combinations of actions	Performance ranks I	Performance ranks II	Performance ranks III
Safety	Failure	Facing*1		Bending moment, Shear force	Permanent action	◎	◎	◎
					Permanent action +Variable action(Train load)	◎	◎	◎
					Permanent action + Variable action (Train load) +seismic action (L1 earthquake motion)	◎	◎	○*6
		Rein-force-ment	Pullout*2 Rapture*3	Pullout force Tensile force	Permanent action	◎	◎	◎
					Permanent action + Variable action (Train load)			
					Permanent action + Variable action (Train load) + seismic action (L1 earthquake motion)			
	Stability	Supporting ground		Settlement (consolidation)	Permanent action	◎	◎	○
				Liquefaction index*4	Permanent action + Variable action (Train load) Permanent action + Variable action (Train load) +Seismic action (L1 earthquake motion)	◎	○	△
		Rein-forced soil	External stability Internal stability*5	Moment Sliding force	Permanent action	◎	◎	◎
					Permanent action + Variable action (Train load)	◎	◎	◎
					Permanent action + Variable action (Train load) +Seismic action (L1 earthquake motion)	◎	◎	○*6
Serviceability	Work-ability of track mainte-nance	Back fill (reinforced soil)		Cumulative deformation quantity	Permanent action Permanent actions+ Variable action	○	△	—
		Supporting ground		Settlement rate (consolidation)		◎	○	○
	Appea-rance	Facing*1		Crack width of concrete facing Stress		◎	◎	○*6
Restorability	Damage	Facing*1		Bending moment Shear force	Permanent action +Seismic action (L2 earthquake motion) Permanent action +Seismic action (L2 earthquake motion) +Secondary variable action	◎	△	—
		Rein-force-ment	Pullout*2 Rapture*3	Pulloutresistance force Tensile force				
	Residual displace-ment, deformation	Residual settlement of the supporting ground*4		Residual displacement		○	△	—
		Residual displacement of reinforced soil				◎	△	—
(Durability)	Corrosion of steel material Degradation of concrete facing Degradation of reinforcement			—	Permanent action	◎	◎	◎

(Legend) ◎ : mandatory, ○ : basicallyto be conducted, △ : to be conducted as necessary, — : generally not necessary
*1 : the examination should comply with the "Design Standard for Concrete Structures"
*2 : including in the stability analysis of reinforced soil
*3 : included in the detailed examinations of the performance of facing
*4 : the examination should comply with "Aseismic design standard"
*5 : taking into account the horizontal/vertical bearing capacities of the foundation
*6 : can be omitted only if the retained backfill does not support a track or tracks directly

2.2.2 Principles of Verification of Satisfactory Performance

(1) In this Manual, satisfactory performance shall be verified in principle by setting a limit state for each item of the performance requirements for geosynthetic-reinforced soil retaining walls (GRS RWs) and by confirming that the retaining walls and their components will not reach such limit state on the basis of the Design Standard for Earth Retaining Structures.

(2) Satisfactory performance of GRS RWs shall be verified by confirming that the set performance requirements will be met, with changes with time in performance during the construction period and the design durable period (i.e., the design life time) taken into consideration.

(3) The verification of satisfactory performance as stipulated in this Manual shall meet the requirements set forth in Section 2.2.7, Durability, and Chapter 7, Construction and Maintenance, of the Design Standard for Earth Retaining Structures.

[Commentary]

With regard to (1), (2) and (3) above:

In this Manual, a detailed examination to verify satisfactory performance shall be conducted by setting a limit state for each item of the performance requirements for geosynthetic-reinforced soil retaining walls (GRS RWs) and by checking to be certain that the GRS RWs and their components will not reach such limit state on the basis of the Design Standard for Earth Retaining Structures. Furthermore, it shall be assumed that the detailed performance examination will meet the requirements set forth in Section 2.2.7, Durability, and Chapter 7, Construction and Maintenance, of the Design Standard for Earth Retaining Structures.

Table 2.2.2-1 Required performance and assumed limit states for "GRS RWs"

[Design Standard for Earth Retaining Structures, Table 3.3.1]

(a) Static design (non seismic conditions)

Required performance	Performance item	Assumed limit state
Safety	Failure	The state in which the resistivity of the earth retaining structure can be maintained without facings, reinforcements, or other structural members of the earth retaining structure failing. For facings, it is based on the 'Design Standard for Concrete Structures.'
	Stability	The state in which stability of earth retaining structure can be maintained without the foundation of the earth retaining structure failing and without loss of stability of the ground/retained ground and the reinforced soil of the reinforced-soil structure.
Serviceability	Workability of track maintenance	The state in which the workability of track maintenance can be maintained with little displacement/deformation of facings, foundation, and retained ground of the earth retaining structure.
	Appearance	The state in which the earth retaining structure can be used without cracks or dirt on the facing surfaces of the earth retaining structure occurring, or even if they do, without providing a feeling of anxiety or discomfort. This is based on the 'Design Standard for Concrete Structures.'
Restorability	Damage	The state in which facings, reinforcements, and other structural members of the earth retaining structure do not get damaged, or the state in which partial damage occurs but can be quickly repaired and functionality can be restored. For facing, it is based on the 'Design Standard for Concrete Structures.'

(b) Seismic design

Required performance	Performance item	Assumed limit state
Failure Stability	Failure	The state in which the resistivity of the earth retaining structure can be maintained without facings, reinforcements, or other structural members of the earth retaining structure failing. For facings, it is based on the 'Design Standard for Concrete Structures.'
	Stability	The state in which the stability of the earth retaining structure can be maintained without the foundation failing despite large residual displacement occurring, and without the loss of stability of the ground/retained ground and reinforced soil of the reinforced-soil structure.
Restorability	Damage	The state in which the facings, reinforcements, and other structural members of the earth retaining structure are nearly undamaged, or the state in which partial damage occurs but can be quickly repaired and functionality can be restored. For facing, it is based on the 'Design Standard for Concrete Structures.'
	Residual displacement	The state in which almost no displacement to the foundation of the earth retaining structure, settlement of ground and deformation of retained ground remain, or the state in which displacement of foundation remains, ground has settled or deformation of the retained ground remains but functionality can be restored quickly even if repairs become necessary.

2.2.3 Method of Verification of Satisfactory Performance

The method of the verification of satisfactory performance specified in this Manual is to set an equivalent limit state for each performance requirement and set a limit value to be examined for each performance requirement and thereby to compare those values with response values. (3.4 of the Design Standard for Earth Retaining Structures.

(1) The verification of satisfactory performance shall be conducted by the method prescribed in 2.2.4, Safety, 2.2.5, Usability, and 2.2.6, Restorability, after calculating design response values as stipulated in Chapter 6, Calculation of Response Values, of the Design Standard for Earth Retaining Structures.

(2) The verification of satisfactory performance shall generally be conducted by the following equation:

$$\gamma_t \cdot \frac{I_{Rd}}{I_{Ld}} \leqq 1.0 \qquad \text{(Equation 2.2.3-1)}$$

where: I_{Rd} : Design response value

I_{Ld} : Design limit value

γ_t : Structure factor of "**2.2.8 Safety Factors**"

[Commentary]

Figure 2.2.3-1 shows the flow of a detailed performance examination.

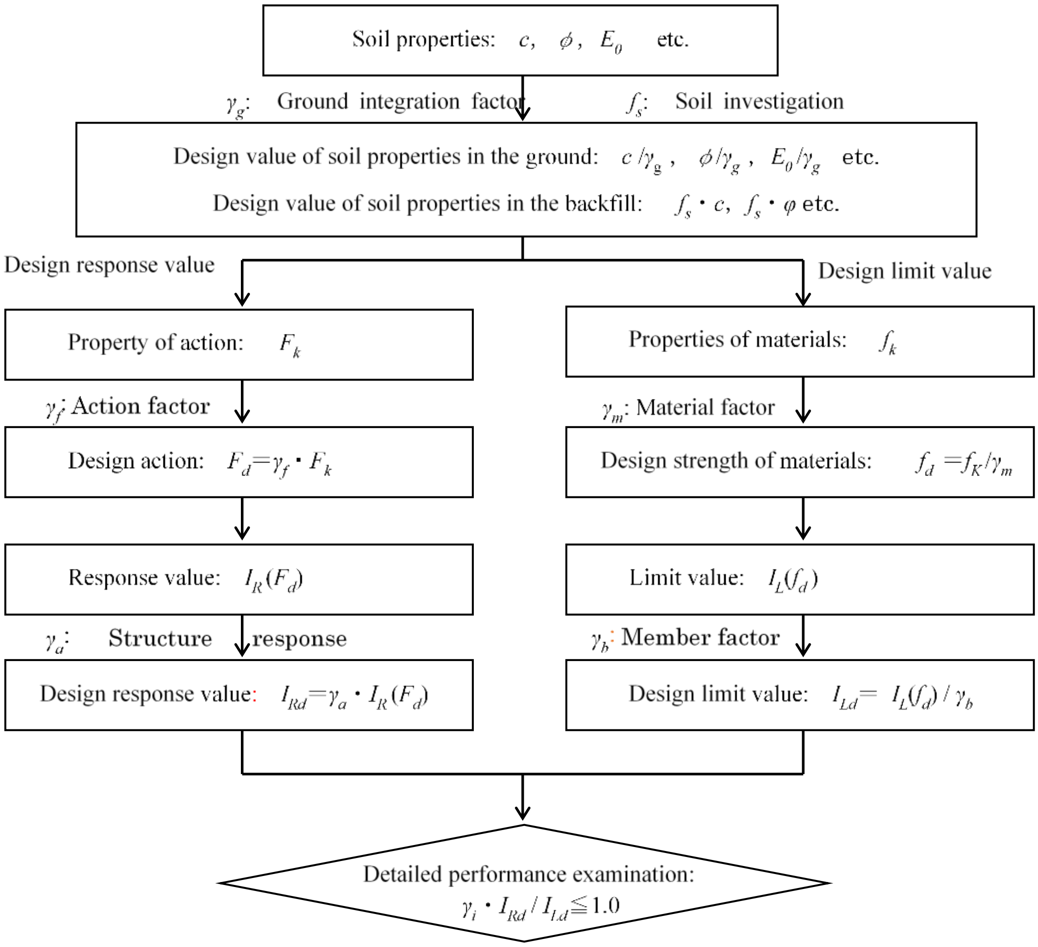


Figure 2.2.3-1 Flow of a detailed performance examination

〔Design Standard for Earth Retaining Structures, Figure 3.4.1〕

2.2.4 Safety (3.5, 8.3.5.2 of Design Standard for Earth Retaining Structures)

The satisfactory performance of a geosynthetic-reinforced soil retaining wall (GRS RW) shall be verified by calculating design response values for the failures of the RC wall facing and the reinforcement and the stability of the supporting ground and the reinforced soil, setting design limit values as determined from the safety of the GRS RW and making a calculation by the equation (2.2.3-1).

(1) A detailed examination concerning the failure of the RC facing of the GRS RW shall be conducted in accordance with by the Design Standard for Concrete Structures.

(2) A detailed examination concerning the failure of the GRS RW shall be conducted with respect to the pull-out and tensile rupture of the reinforcement.

(3) A detailed examination concerning the stability of the supporting ground of the GRS RW shall be conducted in accordance with the Design Standard for Earth Structures.

(4) A detailed examination concerning the stability of the reinforced soil of the GRS RW shall be conducted with respect to internal stability and external stability.

[Commentary]

A detailed examination concerning the safety of a GRS RW shall be conducted by setting design limit values that are determined from the safety of the GRS RW with regard to rupture and stability.

Table 2.2.4-1 shows examples of safety performance items to be taken into consideration in the design of a GRS RW.

Table 2.2.4-1 Examples of performance items to be considered for detailed examination of safety of "GRS RWs"

[Design Standard for Earth Retaining Structures, Table 3.5.1]

Required performance	Performance item	Detailed examination item and indices
Safety	Failure	Cross-sectional force and bending deflection of concrete facing Pullout and rapture of geogrid reinforcement
	Stability	Stability of supporting ground Stability of footing, retained backfill and reinforced soil

Further, with respect to the safety of the facing foundation, a direct detailed examination will not be conducted. In a detailed examination regarding the internal stability of the reinforced soil. On the other hand, a detailed examination shall be carried out concerning sliding, overturning stability and shear deformation taking into account the upper limit values of the horizontal support force and vertical support force of the facing.

2.2.5 Usability (3.6, 8.3.5.3 of Design Standard for Earth Retailing Structures)

The satisfactory usability of a GRS RW shall be verified by calculating design response values for the workability of track maintenance and the appearance of the facing, setting design limit values as determined from the usability of the GRS RW and making a calculation by the equation (2.2.3-1).

[Commentary]

Table 2.2.5-1 shows examples of the performance items of the usability to be considered in the design of a GRS RW.

Table2.2.5-1 Examples of performance items to be considered for detailed examination of serviceability of “GRS RWs”

[Design Standard for Earth Retaining Structures, Table 3.6.1]

Required performance	Performance item	Detailed examination item and indices
Serviceability	Workability of track maintenance＊1	Residual displacement / Settlement rate
	Appearance	Crack width of concrete facing / Stress

＊1 : The workability of track maintenance can be considered to be satisfied by satisfying the bearing capacity of foundation in the “Design Standard for Foundation Structures”' and the serviceability in the ”Design Standard for Concrete Structures”.

2.2.6 Restorability (3.7, 8.3.5.4 of Design Standard for Earth Retailing Structures)

The satisfactory restorability of a reinforced-backfill retaining wall shall be verified by calculating design response values for the damage of the RC facing and the reinforcement and the residual displacement of the support ground and the reinforced soil, setting design limit values as determined with the restorability of the reinforced-backfill retaining wall taken into consideration and making a calculation by the equation (2.2.3-1) as required.

[Commentary]

Table 2.2.6-1 shows examples of the performance items of the restorability to be taken into consideration in the design of the geotextile reinforced soil retaining wall (GRS RW).

Table2.2.6-1 Examples of performance items to be considered for detailed examination of restorability of “GRS RWs”

[Design Standard for Earth Retaining Structures, Table 3.7.1]

Required performance	Performance item	Detailed examination item and indices
Restorability	Damage	Bending deflection of concrete facing Pullout failure, rapture and tensile strain of geogrid reinforcement
	Residual displacement	Residual settlement of supporting ground Residual displacement of reinforced soil

Table 2.2.6-2 shows the performance ranks of the GRS RW and the rough standards for damage levels and displacement levels.

Table 2.2.6-2 Benchmark limit values of the damage level and deformation level for the standard performance ranks of "GRS RWs"

[Design Standard for Earth Retaining Structures, Table 8.3.5-5]

Subject		Performance rank I	Performance rank II
Concrete facing	Damage level	Level 1 to 2	Level 2 to 3
Reinforcement (geotextile)		Level 1[*1]	Level 1[*1]
Reinforced soil Supporting ground	Deformation level	Level 1 to 2[*2]	Level 2 to 3

*1 : Damage level 2 or 3 may be allowed if the reinforcement does not satisfy level 1 by large load acting locally on the wall top such as the foundation of telephone pole etc. (the limit value follows in the case of reinforced soil bridge abutment)

*2 : Deformation level 3 may be allowed with slab track if re-injection of CA mortar can be applied for restoration

Table 2.2.6-3 shows the damage levels of the reinforcement and main possibilities of repair, and Table 2.2.6-4, rough standards for limit values for the damage levels of the reinforcement.

Table 2.2.6-3 Damage level of the reinforcement and example of repair work

[Design Standard for Earth Retaining Structures, Table 8.3.5-2]

	Level of damage	Limit value	Example of repair work
Damage level 1	No damage	Design tensile rupture strength	No repair
Damage level 4	Damage which requires a repair work	Tensile rupture strength higher than design tensile strength	Repair at the connection between the facing and the reinforcement

Table 2.2.6-4 Rough standard of design limit values for limit states assumed for respective damage levels of reinforcement

[Design Standard for Earth Retaining Structures, Table 9.3.5-3]

Damage levels	Assumed limit states	Rough standard of design limit value
1	No damage	Tensile force has not reached the design tensile rupture strength
2	Part of reinforcement has yield and may be needed to repair	Tensile force has reached the design tensile rupture strength and the strain in the reinforcement layers in the upper third of the wall remains below 3 %.
3	Part of reinforcement has yield and may be needed to repair	Tensile force has reached the design tensile rupture strength and the strain in the reinforcement layers remains below 5 %.
4	Part of reinforcement has tensile-ruptured	

Table 2.2.6-5 shows the deformation levels of the retained ground of the retaining wall and main possibilities of repair, and Table 2.2.6-6 shows the extent of damage according to the deformation levels and the rough standards for the amount of settlement.

Table 2.2.6-5 Deformation level and envisioned repair of retained ground of retaining wall

[Design Standard for Earth Retaining Structures, Table 3.7. 3]

	Deformation level of retained ground of retaining wall	Envisioned repair
Deformation Level 1	Almost no deformation occurs, and functionality is sound or can be used without repair.	No repair
Deformation Level 2	Some deformation occurs, but functionality can be restored in a short time (for example, the amount of residual deformation against the assumed actions is small)	- In a maintenance-free track (slab track), minor repairs such as adjustments via track pads are conducted. - In a ballasted track, minor repairs such as replenishments of ballasts are conducted.
Deformation Level 3	Residual deformation is large, but functionality can be restored by partial rebuilding (for example, the amount of residual deformation against the assumed actions is large and partial rebuild is required, but does not reach the point of catastrophic failure)	- In a maintenance-free track, re-injection of CA mortar is conducted. - In a ballasted track, partial removal of backfill or bed surface, rebuild of backfill and track.
Deformation Level 4	Residual deformation is extremely large, and functionality cannot be restored without a total rebuild (for example, amount of residual deformation against the assumed actions is extremely large, and reaches the point of catastrophic failure)	Total removal and rebuild

Table 2.2.6-6 Degree of the damage and benchmark limit values of the settlement deformation on reinforced-backfill

[Aseismic Design Standard, Annexed table 12.6.1]

Deformation level	Degree of the damage	Benchmark limit values of the settlement		
		Ballastless track	Ballast track	
			Embankment*1	Backfill of structure such as abutment or box culvert, etc.
1	No damage	No damage*2		
2	Minimal damage	Settlement, less than 5cm*3	Settlement less than 20cm	Difference by the settlement on the backfill, less than 10cm
3	Damage that restoration is possible by an emergency treatment	Settlement, 5cm or more & less than 15cm*4	Settlement, 20cm or more & less than50cm	Difference by the settlement, 10cm or more & less than 20cm
4	Damage which requires long time for restoration	Settlement, 15cm or more	Settlement, 50cmor more	Difference by the settlement, 20cm or more

＊1：On the detailed examination of residual deformation of the ground behind the retaining wall, it is better to use the benchmark values of this column.
＊2：In this case the benchmark values are set in reference to the standard for track maintenance to determine in each railway company.
＊3：This benchmark value images adjustment by track pad.
＊4：This benchmark value images restoration by re-injection of CA mortar.

2.2.7 Durability (3.8, 8.3.5.5 of Design Standard for Earth Retailing Structures)

(1) A study of the durability of the RC facing shall be made in accordance with the Design Standard for Concrete Structures.

(2) A study of the durability of the reinforcement shall be made properly, with the extent of the actions, environmental conditions, etc. taken into consideration.

[Commentary]

Table 2.2.7-1 shows examples of the performance items of the durability in the design of the GRS RW.

Table 2.2.7-1 Examples of performance items of durability for "GRS RWs"
[Design Standard for Earth Retaining Structures, Table 8.3.5-1]

Required performance	Performance item	Detailed examination indices
Durability	Corrosion of steel material Degradation of concrete facing Degradation of reinforcement	—

An examination of the durability the facing may be omitted if the following conditions are satisfied; of (1) the front side of the RC facing is designed taking into account the specified environment conditions, and (2) the back side of the RC facing is designed and constructed by casting-in-place concrete without using concrete form specified in the Design standard for Concrete Structures. With respect to the geotextile, the effects of alkali resistance, creep, etc. shall be evaluated properly by reference to the 5.6 of the Design Standard for Earth Retaining Structures.

Further, the resistance of concrete against neutralization shall be examined meeting the requirements specified in 10.2.3 of the Design Standard for Concrete Structures, Annexed Document 13.

2.2.8 Safety Factors (3.9 of Design Standard for Earth Retailing Structures)

The following safety factors shall be in accordance with the relevant Design Standards for Railway Structures: the activity coefficient γ_f, structural analysis factor γ_a, materials factor $\gamma_m \cdot f_m$, member factor γ_b, structure factor γ_i, soil survey coefficient γ_s, ground survey coefficient γ_g, ground resistance coefficient f_r, circular slip resistance coefficient f_{rs}, internal stability resistance coefficient f_{ri}, coefficient relating to resistance to the pullout of the reinforcement f_{rg}, and coefficient of skin friction between facing bottom surface and ground f_{rbs}.

[Commentary]

Table 2.2.8-1 through Table 2.2.8-11 show examples of the activity coefficient, structural analysis factor, structure factor, materials factor, materials correction coefficient, member factor, ground survey coefficient, ground resistance coefficient, internal stability resistance coefficient, coefficient relating to resistance to the pullout of the reinforcement, circular slip resistance coefficient and coefficient of skin friction between facing bottom surface and ground which are used for reinforced-backfill retaining walls.

Table 2.2.8-1 Values of action coefficient γ_f used in the design of "GRS RWs"
[Design Standard for Earth Retaining Structures, Table 4.3.1]

Required performance	Principal performance items	Actions	Action coefficient γ_f
Safety Serviceability	Failure, stability	Permanent	1.0~1.2 (0.8~1.0)*
		Primary variable	1.1～1.2
		Secondary variable	1.0
Safety	Bearing capability of foundation, appearance	All actions	1.0
Serviceability	Damage, residual displacement	All actions	1.0

＊ : Smaller values are more disadvantageous

Table 2.2.8-2 Action coefficient γ_f of earth pressure
[Design Standard for Earth Retaining Structures, Table 4.4.1]

Required performance	Types of earth pressure	Action coefficient γ_f
Safety	Earth pressure due to permanent action Earth pressure due to variable action Seismic earth pressure	1.0～1.1 1.0～1.1 1.0
Serviceability	Earth pressure due to permanent action Earth pressure due to variable action	1.0 1.0
Restorability	Earth pressure due to permanent action Seismic earth pressure	1.0 1.0

Table 2.2.8-3 Values of structural analysis factor γ_a used in the design of "GRS RWs"
[Design Standard for Earth Retaining Structures,6.3]

Required performance	Principal performance items	Structural analysis factor γ_a
Safety	Failure, stability	1.0
Serviceability	Appearance	1.0
Restorability	Damage, residual displacement	1.0

Table 2.2.8-4 Values of structure factor γ_i used in the design of Reinforced-backfill retaining walls”

[Design Standard for Earth Retaining Structures,3.9]

Required performance	Principal performance items	Structure factor γ_i
Safety	Failure, stability	1.0~1.2
Serviceability	Appearance	1.0
Restorability	Damage, residual displacement	1.0

Table 2.2.8-5 Values of material factor and member factor used in the design of “GRS RWs”

[Design Standard for Concrete Structure, Table 3.6.2]

Safety factor / Required performance	Material factor		Member factor γ_b
	γ_c	γ_s	
Safety (failure) at the time of other than earthquake	1.3	1.0 (1.05)*1	1.1 (1.2~1.3)*2
Safety (failure) at the time of earthquake	1.3	1.0	1.0 (1.1~1.3)*3
Safety (fatigue estruction)	1.3	1.05	1.0~1.1 (1.3)*2
Serviceability(appearance)	1.0	1.0	1.0
Restorability(damage)	1.3	1.0	1.0 (1.1~1.3)*3

＊1：The value in ( ) applies to steel material to use for a stopper.
＊2：The value in ( ) applies to calculation of shear strength or torsion strength to be decided by strength of concrete.
＊3：The value in ( ) applies to calculation of shear strength.

Table2.2.8-6 Material factor f_{eg} and material correction factor ρ_m of Geotextile

[Design Standard for Earth Retaining Structure, Table 5.6.1]

Items	General actions	Variable actions during construction（including Level 1 seismic load）	Actions including Level 2 seismic load	Remarks
Material correction factor	$\rho_m = 0.8$		$\rho_m = 1.0$	—
Material factor	f_{eg} =0.4~0.7	f_{eg}=0.6~0.95	f_{eg}=0.7~1.0	$f_{eg} = \prod_i \cdot \alpha_i$ depending on types of action, with α_i^* obtained experimentally

＊： α_i denote material reduction factors

Table2.2.8-7 Soil investigation factor γ_g to use for various ground properties
[Design Standard for Foundation Structure, Table 6.4-1]

Design factor of various ground properties	Ground investigation method		Soil investigation factor γ_g
Ground deformation modurous E_d to use for calculation of ground reaction coefficient	Triaxial compression test		1.2~1.4 (1.0~1.1)*
	Unconfined compression test		
	Plate load test	in new loading	1.2~1.4
		in cyclic loading	1.0~1.1
	PS logging		1.0~1.1
	Pressuremeter test in borehole （except glavel）		1.2~1.4
	Standard penetration test （sandy soil）		1.2~1.4

＊: When high quality samples with a little disturbance were collected

Table2.2.8-8 Ground resistance coefficient f_r
[Design Standard for Foundation Structure, Table 13.3.1-3]

(a) Static design (non seismic conditions)

Required performance of structure	Performance item of foundation		Ground resistance coefficient f_r
Safety	Stability of foundation		0.67
Serviceability	Bearing performance	Long-term	0.33
		Long-term	0.50

(b) Seismic design

Required performance of structure	Performance item of foundation	Ground resistance coefficient f_r
Safety	Stability of foundation	0.83
Restorability	Residual displacement	1.00

Table2.2.8-9 Resistance factor for the detailed examinations of the internal stability
[Design Standard for Earth Retaining Structure, Table 8.3.5-3, Table 8.3.5-6]

	Main actions	Internal stability resistance factor f_{rii}	Resistance factor related to the pullout failure of the reinforcement f_{rg}
Safety	Permanent actions	0.50	0.50
	Variable actions	0.67	0.67
	Seismic action (Level 1 seismic ground motion)	0.80	0.80
Restorability	Earthquake action (Level 2 seismic ground motion)	1.00	1.00

Table2.2.8-10 Rotational sliding resistance factor f_{rs}
[Design Standard for Earth Retaining Structure, Table 8.3.5-4]

	Main actions	Rotational sliding resistance factor f_{rs}		
		Performance rank I	Performance rank II	Performance rank III
Safety	Self weight (including during construction)	0.83	0.83	0.91
	Self weight + train load	0.71	0.76	0.76
	Level 1 seismic ground motion	0.83	0.91	1.00

Table2.2.8-11 Facing base-ground friction resistance factor f_{tbs}

	Facing base-ground friction resistance factor f_{rbs}
Sandy soils	1.0
Clayey soils	0.5

2.3 Actions that Are Used in Design

2.3.1 Actions in general

(1) In the verification of satisfactory performance of a geosynthetic-reinforced soil retaining wall (GRS RW), as is set forth in Chapter 4 of the Design Standard for Earth Retaining Structures, the actions (permanent actions, variable actions, and accidental actions) occurring during the construction period and the design durable period (i.e., the design life time) shall be considered in an appropriate combination according to the required performance.

(2) The types of such actions shall include those actions as specified in the Design Standard for Earth Retaining Structures and other Design Standards for Railway Structures as well as a dead load, actions caused by dead loads and earthquakes, actions caused by rainfall, actions caused by freezing and, actions due to variations in train loads.

(3) The values of design actions shall be values obtained by multiplying the characteristic values by the coefficients of actions.

[Commentary]

With regard to (1) above:

The actions that should be considered in detailed performance examination of a GRS RW are generally classified into permanent actions, variable actions and accidental actions according to continuousness, degree of variation and frequency of occurrence. In detailed performance examination, according to performance items and detailed examination indices, these actions shall be appropriately combined.

Here, these actions are classified as follows:

(1) Permanent actions: those actions whose variations are negligibly small and which have a continuous effect.

In the case of earth structures, self weight and dead weight such as track loads are representative examples of these actions. Earth pressure due to self weight is handled as a permanent action. Further, the conditions that can be assumed to exist when trains are parked at a rail yard (a train depot) and a stop track are handled as a permanent action.

(2) Variable actions: those actions occurring frequently or continuously whose variations cannot be ignored.

Variable actions include train loads, impact loads, wind loads, earth pressure due to train loads, and roadbed pressure. The actions relating to the rainfall and freezing-thawing that are expected to occur frequently during the service of the structures are also classified under this category of actions.

(3) Accidental actions: those actions which will take place at a very low frequency but, if they occur, will have a significant effect.

They include the greatest class of earthquake shaking and rainfall.

With regard to (2) above:

The following are the actions used in a detailed performance examination of a reinforced-backfill retaining wall:

1) Permanent actions:
   - (1) Fixed dead weight
   - (2) Additional dead weight
   - (3) Water pressure
   - (4) Earth pressure (as a permanent action)
   - (5) Effect of ground settlement
   - (6) Effect of ground displacement and fulcrum movement
   - (7) Effect of lateral displacement
   - (8) Effect of concrete shrinkage
   - (9) Effect of creep of concrete

2) Major variable actions:
   - (1) Train load
   - (2) Impact load
   - (3) Centrifugal load
   - (4) Car lateral load and car lateral pressure load
   - (5) Braking load and starting load
   - (6) Long rail longitudinal load
   - (7) Effect of lateral displacement
   - (8) Effect of concrete shrinkage
   - (9) Water pressure, buoyancy (high level, low level)
   - (10) Flowing water pressure (high level)
   - (11) Wave force
   - (12) Earth pressure (earth pressure due to variable action)

3) Accidental actions:

(a) Seismic actions:
   - (1) Inertial force at time of earthquake
   - (2) Dynamic water pressure at time of earthquake
   - (3) Earth pressure at time of earthquake
   - (4) Effect of ground displacement at time of earthquake
   - (5) Effect of lateral ground flow caused by liquefaction at time of earthquake
   - (6) Long rail longitudinal load

With regard to (3) above:

The values of design actions shall be values obtained by multiplying the characteristic values of each action by the coefficients of actions. The characteristic values of the actions shall be in accordance with 4.3, Action Coefficients, of the Design Standards for Railway Structures.

2.3.2 Types of Action and Calculation of Characteristic Values

The characteristic values of the actions, (1) to (6) below, shall be calculated for each individual type of action. However, as to the actions that are not covered in this Manual, the calculation of the characteristic values shall be made in accordance with the Design Standards for Railway Structures.

(1) Earth pressure
(2) Water pressure
(3) Dead load
(4) Seismic action
(5) Action due to rainfalls
(6) Action due to freezing

[Commentary]

With regard to (1) above:

In calculating the characteristic values of earth pressure as a permanent action, active earth pressure, passive earth pressure and at-rest earth pressure shall be taken into consideration according to the amount of the displacement and deformation of the geosynthetic-reinforced soil retaining wall (GRS RW). Further, the characteristic value of the earth pressure that will develop due to the effect of seismic actions shall be considered in accordance with the amount of the displacement and deformation of the GRS RW and the magnitude of inertial force.

1) Earth pressure as a permanent action:

The characteristic value of earth pressure as a permanent action working on the GRS RW shall be determined according to the type and rigidity of the structure and the properties of the soil type of the retained backfill. Furthermore, the following earth pressures shall be considered to be earth pressure as permanent action: that is, the earth pressure due to a track load put by the roadbed and the tracks that continuously acts on the retained backfill and the earth pressure occurring due to the surcharge load applied by any associated structure such as a noise barrier wall. Further, in the determination of the value of a track load, at least a load of a track equivalent to a ballasted track (i.e., Shinkansen: 15kgN/m^2; conventional railroad line: 10 kN/m^2) shall be taken into consideration.

a. Active earth pressure as a permanent action:

The characteristic value of active earth pressure shall be calculated by the two-part wedge method of analysis (one of the trial wedge methods). Further, in the case for the part of structure below the ground water level, water pressure as well as earth pressure obtained by using effective unit weight shall be taken into consideration.

b. Passive earth pressure as a permanent action:

The ground resistance (passive earth pressure) of the backfilled soil on the front face of the foundation for the RC facing of the GRS RW shall not be taken into account. In 6.2.4, Modeling of Retained Ground, of the Design Standard for Earth Retaining

Structures, it is stated that the ground resistance of the backfilled soil on the front face of the foundation for the RC facing of the GRS RW may be taken into account only if the backfilled soil conforms to the requirements for the selection of backfilling materials and the management of construction work. In the case of GRS RW, however, since the thickness of backfilled soil is small, the ground resistance shall not be taken into account.

c. At-rest earth pressure:

In a detailed examination of the performance of the RC facing and the reinforcement, at-rest earth pressure shall be used the design earth pressure. The characteristic value of the at-rest earth pressure working on the facing shall be calculated by the equations shown below. The coefficient of at-rest earth pressure, K_o, in the equations shall be calculated by using Jaky's formula (K_o=1-sinΦ). If the exact value of the internal frictional angle, ϕ, of the retained natural ground is not known, the coefficient of at-rest earth pressure shown in Table 2.3.2-1 may be used.

$$p_0 = \gamma \cdot h \cdot K_0 + q \cdot K_0 \qquad \text{(Equation 2.3.2-1)}$$

$$p_0 = \frac{1}{2}\gamma \cdot h^2 \cdot K_0 + h \cdot q \cdot K_0 \qquad \text{(Equation 2.3.2-2)}$$

where p_o : Earth pressure at rest (per unit area in the vertical plane of projection of the structure) (kN/m^2)

P_o : Total earth pressure at rest (per unit width of the structure) (kN/m)

K_o : Coefficient of earth pressure at rest

h : Depth from the ground surface to the position for which the (total) earth pressure at rest is calculated (m)

γ : Unit weight of soil (kN/m^3)

q : Uniformly distributed load per unit surface area (kN/m^2)

Table2.3.2-1 Coefficient of earth pressure at rest K_0
[Design Standard for Earth Retaining Structure, Table 4.4.2]

	Soil type		K_0
Clayey soils	hard	$8 \leqq N$	0.5
	intermediate	$4 \leqq N < 8$	0.6
	soft	$2 \leqq N < 4$	0.7
	very sof	$N < 2$	0.8
Sandy soils	very dense	$50 \leqq N$	0.3
	dense	$30 \leqq N < 50$	0.4
	loose to medium dense	$N < 30$	0.5

* N denotes SPT-N value

2) Earth pressure due to variable actions (4.4.2.2 of Design Standard for Earth Retaining Structures):
The earth pressure due to variable actions (train load etc.) to be considered in the design of the GRS RW shall be considered as an additional one to the earth pressure developed from the earth pressure that works as a permanent action. Furthermore, in the calculation of the earth pressure due to variable actions that is used in the design, a train load shall be taken into consideration as a surcharge load on the retained backfill (Table 2.3.2-1 and Table 2.3.2-2).
In this case, the value of a train load may be calculated by the formula (Equation 2.3.2-3). Also, in the case where the tracks are close to the wall face, the value of the train load of $B \leq B_o/2$ shall be calculated by the formula (Equation 2.3.2-4). Further, in this case, if the calculation is affected by the centrifugal load and train load in any curved section or the wheel lateral load, it is necessary to give a due additional consideration.

$$q_t = P/(a \cdot B_0) \qquad \text{(Equation 2.3.2-3)}$$

where q_t : Uniformly distributed surcharge load equivalent to the train load per track (kN/m^2)
P : Axle load (kN)
a : Distance between axles (m)
B_0 : Train load distribution width (m) (refer to Table 2.3.2-2)

Table 2.3.2-2 Train load distribution width (per track)
[Design Standard for Earth Retaining Structure, Table4.4.3]

Load width B_0 (m)	
Conventional lines	3.8
High-speed train lines	4.3

$$q_t' = P/(a \cdot B) \qquad \text{(Equation 2.3.2-4)}$$

where P: Axle load (kN)
a: Distance between axles (m)
B: Distance from the wall face to the center of tracks (m)
(refer to Figure 2.3.2-2).

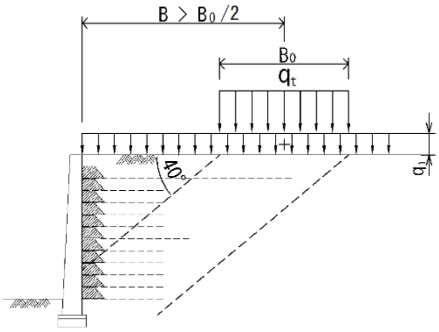


Figure 2.3.2-1 Size and distribution of surcharge (Railroad track is far from the wall face)

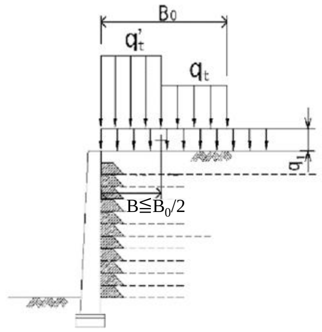


Figure 2.3.2-2 Size and distribution of surcharge (Railroad track is close to the wall face)

3) Earth pressure at the time of an earthquake (4.4.2.3 of the Design Standard for Earth Retaining Structures)
The characteristic value of the active earth pressure shall be determined by taking account of the effect of the reinforcement in addition to the magnitude of inertial force acting on the backfill, the type of the structure and its response value, and the properties of the backfill. The active earth pressure at the time of an earthquake that is used for a detailed examination of stability and displacement shall be calculated by the two-part wedge method.
In the case of level-2 earthquake motion, the peak strength (Φ_{Peak}) shall be used for the used, together with the residual strength (Φ_{res}), in the earth pressure calculation, taking into account that the value of Φ_{Peak} is controlled by the degree of compaction of the backfill material. In the case of level-1 earthquake motion, the residual strength (Φ_{res}) shall be used. On the other hand, in a detailed examination of the performance of the RC wall facing and the reinforcement, the earth pressure at the time of an earthquake shall be calculated by the Equation 2.3.2-5 and the Equation 2.3.2-6 by increasing linearly the static earth pressure as calculated by Jaky's formula ($K_0 = 1 - \sin\Phi$).

$$p_0 = \gamma \cdot h \cdot K_0(1 + k_h) + q \cdot K_0 \quad \text{(Equation 2.3.2-5)}$$

$$p_0 = \frac{1}{2}\gamma \cdot h^2 \cdot K_0(1 + k_h) + h \cdot q \cdot K_0 \quad \text{(Equation 2.3.2-6)}$$

where p_o : Earth pressure at rest (per unit area in the vertical plane of projection of the structure) (kN/m^2)

P_o : Total earth pressure at rest (per unit width of the structure) (kN/m)

K_o : Coefficient of earth pressure at rest

k_h : Design horizontal seismic coefficient

h : Depth from the crest of the backfill to the position for which the (total) earth pressure at rest is calculated (m)

γ : Unit weight of soil (kN/m^3)

q : Uniformly distributed load per unit surface area at the crest of backfill (kN/m^2)

<u>With regard to (2) above:</u>

With respect to the GRS RW, it shall be assumed that drainage works will be constructed appropriately and maintained properly while in service and that water pressure will not work on the structure on the premise that the temporary holding at the wall face will function as a vertical drain layer.

<u>With regard to (3) above:</u>

Dead loads shall be calculated under two categories: fixed dead loads (D_1) and additional dead loads (D_2). Moreover, generally, the characteristic value of dead loads may be calculated by using the unit volume weight of the reinforced concrete, reinforced backfill and ground. Further, it is preferable that the unit volume weight of the ground be based on the results of the soil investigation conducted as part of prior surveys.

- Reinforced concrete: 24.5 kN/m^3 (Design Standard for Concrete Structures)

Table2.3.2-3 Unit weight γ_t of the backside fill
[Design Standard for Earth Retaining Structure, Table5.4.1, Table5.4.2]

Soil type	Classification according to the Japanese Geotechnical Society	Unit weight γ_t (kN/m^3)	
		Values used in the calculation of earth pressure	Values used in the examination of stability
1	G, G-S, GS G-F, G-FS, GS-F hard rock (low fissility)	20	18
2	S, S-G, SG S-F, S-FG, SG-F hard rock (high fissility), soft rock, soft brittle rock	19	17
3	GF, GF-S, GFS SF, SF-G, SFG	18	16
4	ML, CL, MH, CH OL, OH, OV, Pt, Mk VL, VH1, VH2	16	14

＊1：Unit weight γ_t shows saturated unit weight γ_{sat} of embankment.
＊2：For soil type 1 , the compacting images level of performance rank Ⅰ.
＊3：For soil type 2~4, the compacting images level of performance rank Ⅱ or Ⅲ.

Table2.3.2-4 Caracteristic value of unit weight of soil (kN/m^3)
[Design Standard for Foundation Structure, Table 6.4-2]

	N-value	Unit weight (kN/m^3)		
		Wet	Saturated	Submerged
Sandy soils	50 or more 30~50 10~30 less than 10	19 18 18 18	20 19 19 19	10 9 9 9
Clayey soils	10 or more less than 10	16 16	17 16	7 6

With regard to (4) above:
The principle is that seismic actions other than earth pressure at the time of an earthquake that are used in a detailed performance examination shall be in accordance with the Aseismic Design Standard. These seismic actions shall be determined properly taking into consideration the design durability period (i.e., the design life time), the characteristics of the retaining structures and the region in which the structure is to be constructed. Design seismic motion shall be based on the Aseismic Design Standards, and seismic waveform shall be the ground motions according to the ground type that are used in the calculation of the residual deformation and displacement by the Newmarak method shown in Figure 2.3.2-3 while taking into account the coefficients for respective regions.

Further, inertial force shall be obtained by multiplying the dead weight of the RC wall facing and the associated structures, track load, surcharge load, and train load by the horizontal seismic coefficient k_h. Principally, the inertial force shall be calculated by using the maximum acceleration of L1 earthquake motions on the ground surface as set forth in the Aseismic Design Standard. However, the design horizontal seismic coefficient may generally be set at k_h=0.2.

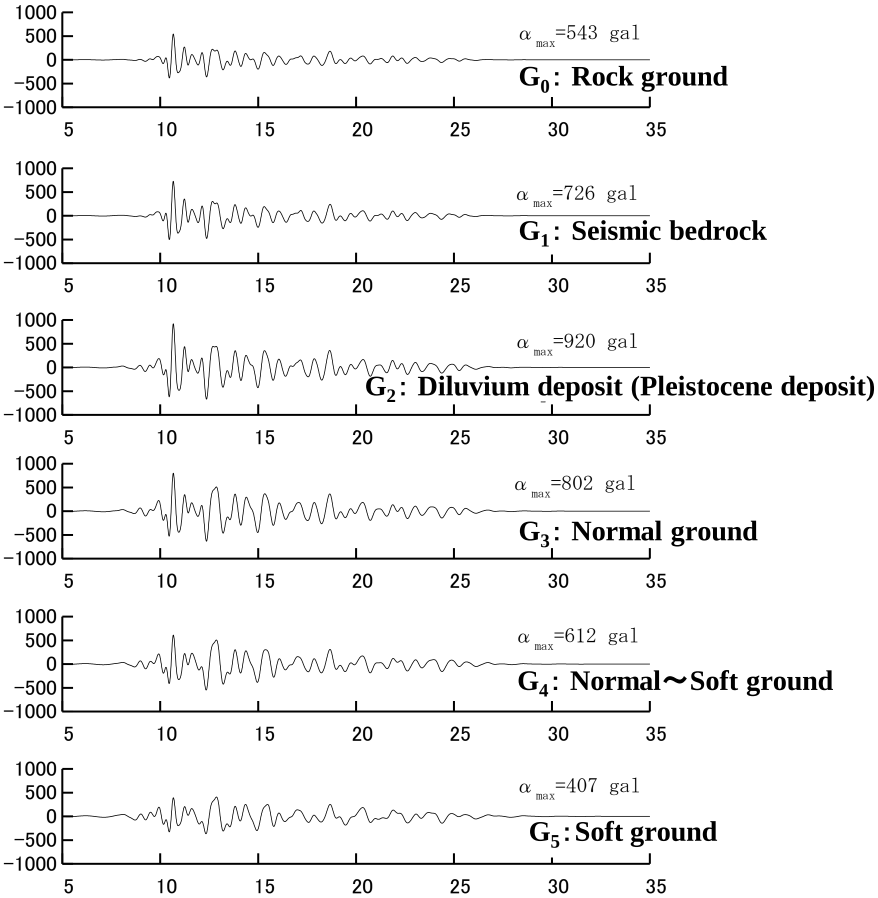


Figure 2.3.2-3 Design seismic ground motions to be used for the Newmark method
[Design Standards for Railway Structures, Annexed figure 12.2.4]

With regard to (5) above:
The action due to rainfall that is used in the detailed performance examination shall be determined properly by taking into consideration the design durable period (i.e., the design life time), the characteristics of the earth retaining structure and the region, among other things.
However, with the GRS RW, on the premise that drainage works will be constructed appropriately and maintained properly while in service, a rise in the water level due to localized heavy rainfall and long-term rainfall shall not in principle be taken into account in conducting the detailed performance examination. Yet, rainfall may have a significant effect at locations of locally water collecting landform or locations in which there is a large amount of welling

water or infiltrating water from the natural ground. In this case, it is necessary to take account of water pressure due to a ground water level rise in conducting a detailed examination.
Further, it is very rare that a large earthquake such as level 2 earthquake motion and a heavy rainfall that may rarely occur during the design durable period will take place at the same time. Accordingly, in general, it is not necessary to take the simultaneous actions of the inertial force due to level 2 earthquake motion and heavy rainfall into consideration.

With regard to (6) above:
The action due to freezing shall not in principle be taken into special consideration except in any case where freezing may have an effect in wintertime construction in a cold region.

2.3.3 Combinations of Design Actions

The combinations of design actions of the geotextile- reinforced soil retaining wall (GRS RW) shall be determined properly in accordance with the Design Standards for Railway Structures that are related to performance requirements.

[Commentary]
The combinations of the actions to be considered in a detailed performance examination of the GRS RW shall be set by reference to Table 8.3.5-1 of Design Standard for Earth Retaining Structures and Table 4.5.2 of Design Standard for Earth Retaining Structures according to individual performance items.

Table2.3.3-1 Combination of actions and examples of act factor for “GRS RWs”

Required performance	Performance item			Detailed exanunation indices	Kinds of action														Remarks (case name of action)
					Parmanent action						Variable action				Seismic action				
															L1 load		L2 load		
					Wall load	Embankment load	Sound barrier load	Track load	Upper load	Earth pressure as permanent action	Train load	Wind load	Electric pole load	Earth pressure by variable actions	Earth pressure in seismic condition	Inertial force in seismic condition	Earth pressure in seismic condition	Inertial force in seismic condition	
					D_1	D_1	D_1	D_2	D_2	E_D	L	W	D_E	E_L	E_{QE}	E_{QT}	E_{QE}	E_{QT}	
Safety	Failure	Failure of wall		Bending moment Shear force	1.1	1.1	1.1	1.2	1.2	1.0	1.1	1.0	1.0	1.1	－	－	－	－	Wall－①
					1.1	1.1	1.1	1.2	1.2	1.0	－	1.2	1.0	－	－	－	－	－	Wall－②
					1.0	1.0	1.0	1.0	1.0	－	1.0	－	1.0	1.0	1.0	1.0	－	－	Wall－③
		Reinforce-ment	Pullout failure	Resistance force related to the pullout failure Design tensile strength	1.0	1.0	1.0	1.0	1.0	1.0	－	－	1.0	－	－	－	－	－	Reinforcement－①
					1.1	1.1	1.1	1.2	1.2	1.0	1.1	1.0	1.0	1.1	－	－	－	－	Reinforcement－②
					1.1	1.1	1.1	1.2	1.2	1.0	－	1.2	1.0	－	－	－	－	－	Reinforcement－③
					1.0	1.0	1.0	1.0	1.0	－	1.0	－	1.0	1.0	1.0	1.0	－	－	Reinforcement－④
	Safty	Reinforced embank-ment	External stability (Circular slip)	Moment	1.0	1.0	1.0	1.0	1.0	－	－	－	1.0	－	－	－	－	－	External stability－①
					1.1	1.1	1.1	1.2	1.2	－	1.1	1.0	1.0	－	－	－	－	－	External stability－②
					1.1	1.1	1.1	1.2	1.2	－	－	1.2	1.0	－	－	－	－	－	External stability－③
					1.0	1.0	1.0	1.0	1.0	－	1.0	－	1.0	－	－	1.0	－	－	External stability－④
			Internal stability (Sliding Stability (Overturning Stability)	Force ･Moment	1.0	1.0	1.0	1.0	1.0	1.0	－	－	1.0	－	－	－	－	－	Sliding (Overturning) stability－①
					1.1	1.1	1.1	1.2	1.2	1.0	1.1	1.0	1.0	1.1	－	－	－	－	Sliding (Overturning) stability－②
					1.1	1.1	1.1	1.2	1.2	1.0	－	1.2	1.0	－	－	－	－	－	Sliding (Overturning) Stability－③
					1.0	1.0	1.0	1.0	1.0	－	1.0	－	1.0	1.0	1.0	1.0	－	－	Sliding (Overturning) stability－④
Service-ability	Appearance	Wall		Crack width Stress	1.0	1.0	1.0	1.0	1.0	1.0	－	－	1.0	－	－	－	－	－	Wall－④
					1.0	1.0	1.0	1.0	1.0	1.0	1.0	－	1.0	1.0	－	－	－	－	Wall－⑤
Restorability	Damage	Damage of wall		Bending moment Shear force	1.0	1.0	1.0	1.0	1.0	－	－	－	1.0	－	－	－	1.0	1.0	Wall－⑥
		Damage of reinforce-ment	Pullout failure	Resistance force related to the pullout failure Design tensile strength	1.0	1.0	1.0	1.0	1.0	－	－	－	1.0	－	－	－	1.0	1.0	Reinforcement－⑤
	Residual deformation	Residual deformation of reinforced embankment		Residual deformation	1.0	1.0	1.0	1.0	1.0	－	－	－	1.0	－	－	－	1.0	1.0	Residual deformation－①
(Durability examination)	Corrosion of steel materials Degradation of wall concrete			－	1.0	1.0	1.0	1.0	1.0	1.0	1.0	－	1.0	－	－	－	－	－	Wall－⑦
	Reinforcement degradation*			－	1.0	1.0	1.0	1.0	1.0	1.0	1.0	－	1.0	－	－	－	－	－	Reinforcement－⑥

*:Because reinforcements listed in ["RRR-B Method Materials manual" June 2011, translated by Antoine Duttine, IGI] are chosen, the examination may be omitted generally.

Further, in this Manual, in the examination of safety and recoverability track loads, etc. (permanent actions) and train loads (secondary variable actions) shall be considered as the surcharge loads on the retained backfill.

2.4 Materials and Ground

2.4.1 Various Design Numerical Values of Retained Backfill

(1) For the retained backfill of the geosynthetic-reinforced soil retaining wall (GRS RW), materials of proper quality shall be selected in accordance with the Design Standard for Earth Retaining Structures and the Design Standard for Earth Structures.

(2) The proper characteristic values and the various design numerical values of the retained backfill shall be determined in accordance with 5.4 of Design Standard for Earth Retaining Structures, by taking into consideration the type of retained backfill materials, rolling compaction conditions, compaction properties, strength/deformation properties, etc.

[Commentary]

With regard to (1) above:

With respect to the design values of the retained backfill of the GRS RW, it is difficult to determine the characteristic values and design values of the retained backfill as concrete, steel materials, etc. For this reason, the basic principle shall be that the selection of materials and investigation/material tests should be carried out first and then, with the accuracy and quantities thereof taken into account, proper characteristic values and design values should be determined. However, if the selection of materials based on investigation and material tests cannot be carried out in advance, standard values should be set and may be used on the assumption that a proper selection of the backfill material and appropriate construction management will be conducted. Further, the basic principle shall be that the backfill materials shall be such that they will be the materials that are specified in 3.2.1 of the Design Standard for Earth Structures and the degree of compaction set forth in 3.2.3 of the Design Standard for Earth Structures will be achieved.

With regard to (2) above:

Generally, the quality of the backfill materials and compaction control could be largely uneven, so it is not easy to determine their design values with taking account of the effects thereof. For this reason, in this Manual, it shall be allowed to use Table 2.4.1-1 for earth pressure calculation, and the values shown in Table 2.4.1-2 for the detailed examination of stability (i.e., circular slip analysis).

Table 2.4.1-1 Values for the design of backfill used in the calculation of earth pressure acting on earth retaining structures（Internal stability）(note: c=0)

[Design Standard for Earth Retaining Structure, Table 5.4.1]

Soil type	Classification according to the Japanese Geotechnical Society	γ_t (kN/m^3)	Seismic (Level 2) *6		Static or seismic (Level 1)
			ϕ_{peak} (deg)	ϕ_{res} (deg))	ϕ (deg)
1	G, G-S, GS G-F, G-FS, GS-F*1 hard rock (low fissility)	20	55	40	40
2	S, S-G, SG*2 S-F, S-FG, SG-F*3 hard rock (high fissility), soft rock, soft brittle rock*4	19	50	35	35
3	GF, GF-S, GFS SF, SF-G, SFG*5	18	45	30	30
4	ML, CL, MH, CH OL, OH, OV, Pt, Mk VL, VH1, VH2	16	40	30	30

*1 : for G-F, G-FS, GS-F soils comprising organic fines, ϕ values of soil type 2 shall be used.
*2 : for well graded S, S-G, SG soils (Uc≥10 or 1<Uc'≤$\sqrt{Uc}$), ϕ values of soil type 1 shall be used.
*3 : for S-F, S-FG, SG-F soils comprising silt or clayey fines, ϕ values of soil type 1 shall be used.
*4 : for viscous, muddy, or weathered soft brittle rocks, ϕ values of soil type 4 shall be used.
*5 : for SF, SF-G, SFG soils comprising organic fines, ϕ values of soil type 4 shall be used.
*6 : soil types 1, and 2~4 are presumed to be consistent with a degree of compaction D_c compatible with a performance rank I, and II to III, respectively. For D_c<90%, only ϕ_{res} values shall be used and ϕ_{peak} values shall be disregarded (i.e. $\phi_{peak}=\phi_{res}$).

Table 2.4.1-2 Values for the design of backfill used in the examination of stability of embankment behind earth retaining structure（External stability）

[Design Standard for Earth Retaining Structure, Table 5.4.2]

Soil type	Classification according to the Japanese Geotechnical Society	γ_t (kN/m^3)	c (kN/m^2)	ϕ (deg.)
1	G, G-S, GS G-F, G-FS, GS-F*1 hard rock (low fissility)	18	6	45
2	S, S-G, SG*2 S-F, S-FG, SG-F*3 hard rock (high fissility), soft rock, soft brittle rock*4	17	6	40
3	GF, GF-S, GFS SF, SF-G, SFG*5	16	6	35
4	ML, CL, MH, CH OL, OH, OV, Pt, Mk VL, VH1, VH2	14	20	25

*1 : for G-F, G-FS, GS-F soils comprising organic fines, c and ϕ values of soil type 2 shall be used.
*2 : for well graded S, S-G, SG soils (Uc≥10 or 1<Uc'≤$\sqrt{Uc}$), c and ϕ values of soil type 1 shall be used.
*3 : for S-F, S-FG, SG-F soils comprising silt or clayey fines, c and ϕ values of soil type 1 shall be used.
*4 : for viscous, muddy, or weathered soft brittle rocks, c and ϕ values of soil type 4 shall be used.
*5 : for SF, SF-G, SFG soils comprising organic fines, c and ϕ values of soil type 4 shall be used.

2.4.2 Various Design Values of Supporting Ground

For the supporting ground of the reinforced-backfill retaining wall, proper characteristic values and design values of the various materials shall be determined on the basis of the results of the ground investigation and the ground materials tests in accordance with the Design Standard for Earth Retaining Structures and the Design Standard for Foundation Structures.

[Commentary]

Proper characteristic values of the various materials of the GRS RW such as the cohesion, internal friction angle, unit volume weight and deformation coefficient of the supporting ground of the GRS RW greatly depend on the accuracy and reliability of the ground investigation and the ground material test. For this reason, the design values shall be obtained by dividing the characteristic values by the ground investigation coefficient, γ_g, which represents the degree of accuracy and reliability, in accordance with 5.3 of the Design Standard for Earth Retaining Structures.

2.4.3 Combinations of Design Actions

The reinforcement that is used for the GRS RW shall be a material of which the proper quality has been be verified. The proper characteristic value and design value of the reinforcement shall be set by taking into consideration variations in various materials test values, installation conditions, etc. Furthermore, in the selection of the reinforcement, an appropriate material shall be selected from among those materials set forth in the Materials Manual.

[Commentary]

It shall be standard practice to use the geotextile for the reinforcement of the GRS RW. The design tensile strength, T_d, of the geotextile shall be set for respective individual action conditions by multiplying the specification value of the tensile strength by the material modification factor and the materials factor. Since the specification value of tensile strength, characteristic values and materials factor of geotextile differs from manufacture to manufacture, its selection shall be made in accordance with the Materials Manual, by taking into consideration the design tensile strength, mesh size, workability, etc.

For reference, Table 24.3-2 gives examples of the design values of a geotextile, a generally used Ta=30 (kN/m) product.

Table 2.4.3-1 Determination of design tensile strength T_d of reinforcement
[Design Standard for Earth Retaining Structure, Table 5.6.1]

Item	General actions	Variable actions during construction including Level 2 seismic load	Actions including Level 2 seismic load	Remarks
Standard tensile strength	T_k (kN/m)			determined taking into account variability
Material correction factor	ρ_m = 0.8		ρ_m = 1.0	
Characteristic tensile strength	$T_a = \rho_m \cdot T_k$ (kN/m)			
Material factor	f_{eg}=0.4~0.7	f_{eg}=0.6~0.95	f_{eg}=0.7~1.0	$f_{eg} = \prod_i \alpha_i$ depending on types of action, with α_i* obtained experimentally
Design tensile strength	$T_d = f_{eg} \cdot T_a$ (kN/m)			

＊: α_i denote material reduction factors（cf. [" RRR-B Method Materials manual " June 2011, translated by Antoine Duttine, IGI]）

Table 2.4.3-2 Example of value for design of geotextile（T_k＝37.5 kN/m）

Kinds of limit state	Safety			Serviceability		Restorability
	Self weight during construction	Train load	Seismic action (Level 1)	Self weight	Train load	Seismic action (Level 2)
Standard tensile strength T_k	37.5 kN/m					
Material correction factor ρ_m	0.8			0.8		1.0
Characteristic tensile strength T_a	30 kN/m			30 kN/m		37.5 kN/m
Material factor f_{eg}	0.6	0.7	0.8	0.6	0.7	0.8
Design tensile strength (kN/m)	18	21	24	18	21	30
Elastic modulus for calculation of stress applied to the wall surface Ks (kN/m)	200					

2.4.4 Characteristic Values and Design Values of Concrete, Steel Materials, Etc.

The concrete, steel materials, etc. that are used for the RC wall facing and foundation of the facing for the geosynthetic-reinforced soil retaining wall (GRS RW) shall be materials of which the quality has been verified in accordance with the Design Standard for Earth Retaining Structures and related Design Standards for Railway Structures. The proper characteristic values and design values of those materials shall be set by taking into consideration variations in test values, installation conditions, etc.

[Commentary]

Proper materials shall be selected for the concrete, steel materials, etc. that are used for the RC wall facing and the foundation of the facing for the GRS RW in accordance with the Design Standard for Concrete Structures, the Design Standard for Steel and Composite Structures and the Design Standard for Foundation Structures, and their proper characteristic values and design values shall be set. However, if any concrete, steel materials, etc. that are shown in the Design Standards for Railway Structures are used, the characteristic and design values shown in these Design Standards may be used.

2.5 Structural Details

The GRS RW shall be constructed with the following items arranged under standard specifications:

(1) Seams of the reinforcement (geotextile)
(2) Foundation
(3) Embedded depth
(4) Wall facing
(5) Mesh size
(6) Temporary holding at wall face
(7) Drainage works

[Commentary]

With regard to (1) above:

It is preferable that the geotextile reinforcement be a single-piece material and be seamless. However, it is unavoidable that, depending on the shape of the material and its dimensions, it will have seams. The principle for the handling of such seams shall be as described below.

It has to be made sure that, in the reinforcement zone, there will be no seams in the direction perpendicular to the facing (i.e., the principal direction). On the other hand, there will inevitably occur for seams to exist in the direction in parallel to the wall face (i.e., the transverse direction). Since the mutual transmission of force is not basically assumed in this direction, the geotextile shall be arranged, with geotextile pieces overlapping each other by 100 mm or so (Fig. 2.5.1-1).

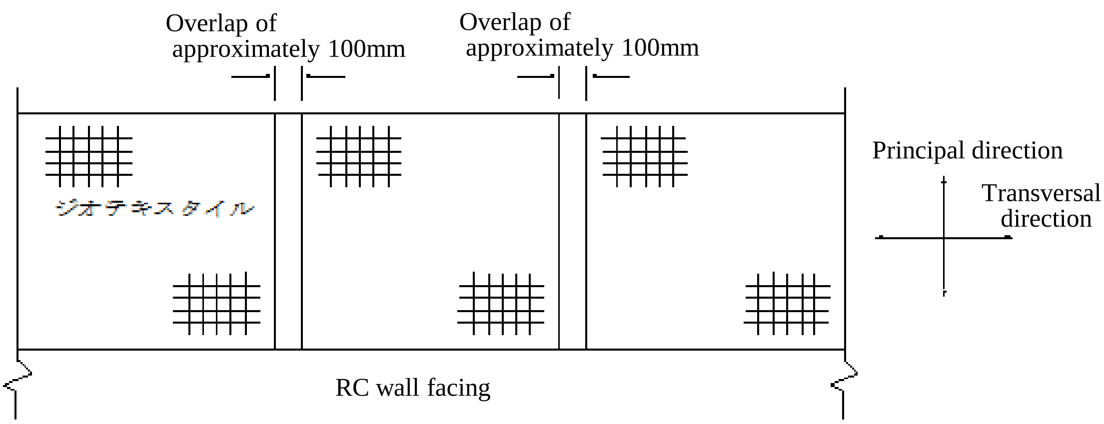


Figure 2.5.1-1 Over-lapping of geotextile sheets

In any case where seams unavoidably have to be made in the principal direction in any section where the geotextile is laid over the entire width of the backfill of a GRS RW having two wall faces, the geotextile pieces shall be overlapped each other by 500 mm or so and connected with annealed wire, etc. In any section where long geotextile layers are laid, as shown by the schematic diagram Fig. 2.5.1-2, they should be laid extended to the line of repose angle, unlike the short geotextile layers laid in the standard way. Further, in this case again, care has to be taken that there will no seams in the principal direction inside the main reinforcing section. The main reinforcing section refers to the inside of the slip line that will give a minimum safety factor in the following two types of stability calculation:

i) Main reinforcing section requiring sufficient internal stability (inside the critical 2 wedges)
ii) Main reinforcing section requiring sufficient external stability (inside the critical circular slip plane)

In many cases, the geotextile is cut to specified dimensions at the site. It is necessary to select proper equipment to be used in the cutting of the geotextile.

It is necessary for the geotextile inside the main reinforcing section to exert the specified anchorage strength (i.e., the pull-out strength) that is equal to, or higher than the rupture strength of the geotextile. In other words, the geotextile should not be pulled out from the zone outside the critical slip plane until the geotextile ruptures at the critical slip plane. This necessary anchorage length (i.e., pull-out length), L, is calculated by the following equation:

$$(\text{Anchor strength } T) / (\text{Resistance factor related to the pullout failure } f_{rg}) = (\text{Rupture strength } T_k),$$

$$L = T_k / (2 \times \sigma_v \cdot \tan\phi \cdot f_{rg})$$

where L : Anchorage length of geotextile layer (m)

σ_v : Effective vertical stress acting on geotextile layer

ϕ : Internal friction angle (°) of backfill material

f_{rg} : Resistance factor related to the pullout failure (Table 2.2.8-9)

Accordingly, in any section where the long geotextile layers are laid, a connection may be provided in the principal direction unavoidably in the back end part of the geotextile as shown in Fig. 2.5.1-2. In this case, the strength (tensile strength) of the connection of the geotextile needs to be equal to, or higher than, the tensile strength of the geotextile itself. If the strength of the connection is lower than that of the geotextile itself, it is necessary to make a detailed examination again, while reducing the design rupture strength of the connection.

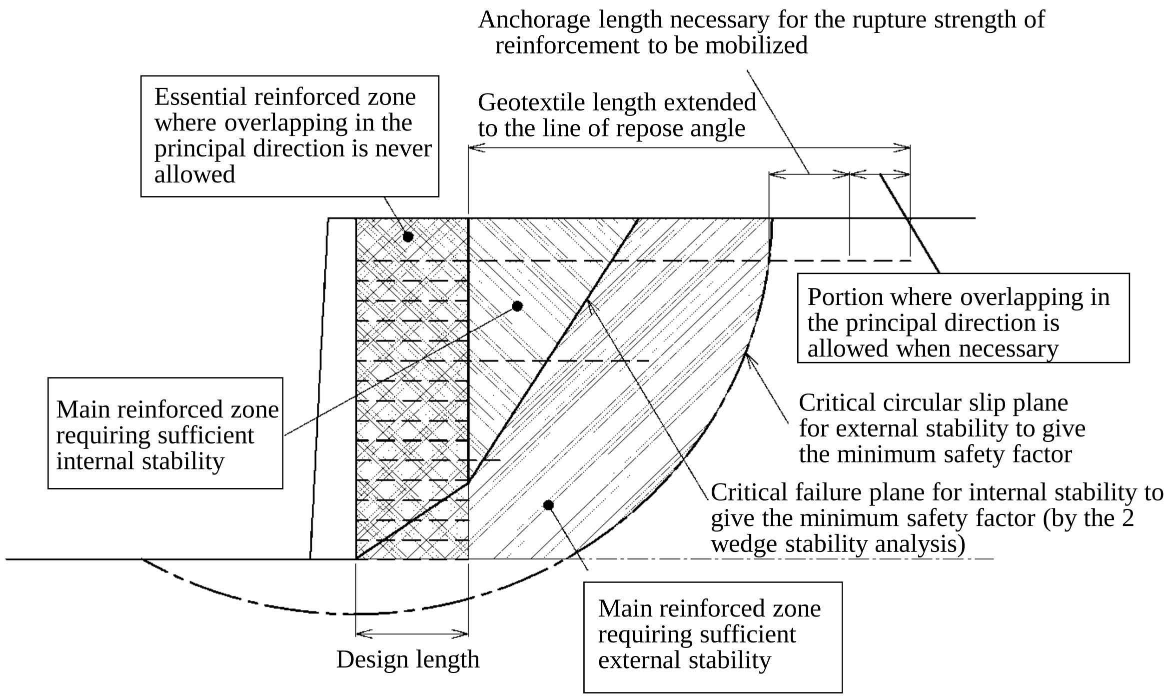


Figure 2.5.1-2 Explanation schematic view about connection of geotextile sheets

With regard to (2) above:

Foundation works play an important role in supporting the dead weight of the RC wall facing and ensuring the accuracy of the wall face alignment. Accordingly, adequate consideration shall be given to the bearing capacity, settlement, etc. to meet the conditions of the ground. Fig. 2.5.1-3 shows the groundwork that generally meets the requirement of external stability.

Levelling concrete shall be used for a foundation work that is installed on ground having an uneven surface.

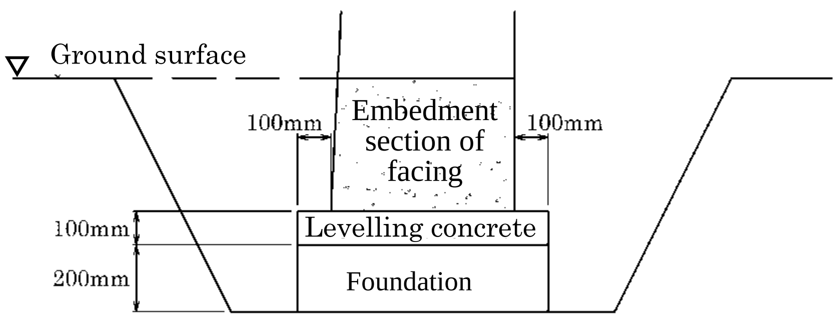


Figure 2.5.1-3 Foundation for RC wall facing

With regard to (3) above:

It shall be ensured that the embedded depth of the wall facing will be 400 mm or more. If excavation is assumed for any drainage work to be installed in front of the wall facing after the construction of the GRS RW, the embedded depth shall be made deeper than the depth of excavation, D_a (Fig. 2.5.1-4).

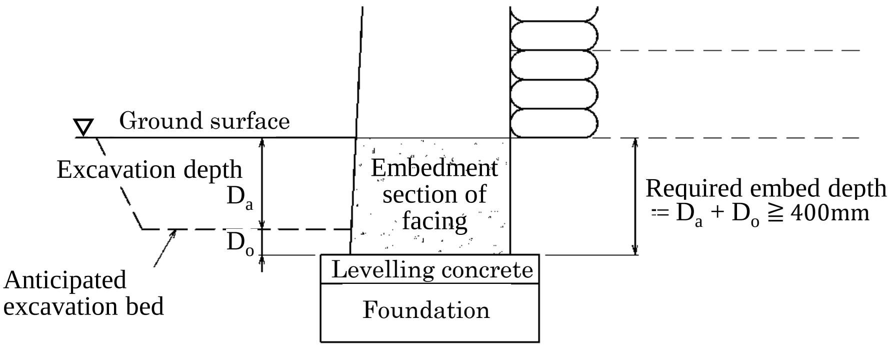


Figure 2.5.1-4   Setting depth of the facing

With regard to (4) above:

The minimum thickness of the wall facing of the GRS RW is as specified in 2.1.3 (i.e., assumptions for Detailed Examination Made under the RRR-B Construction Method). The thickness at each elevation of the wall facing with this minimum thickness taken as basic shall be determined properly by taking account of errors in the construction of the retained backfill, etc. Furthermore, in construction, construction management shall be conducted so that a calculated cross-section (or minimum thickness) will be secured.

In addition, the requirements for the assumptions for a detailed examination and structural details that are described in the Design Standard for Concrete Structures shall be met as required. The main items of the assumptions for a detailed examination and structural details that are described in the Design Standard for Concrete Structures are as follows:

1) Insulation covering (11.2 of the Design Standard for Concrete Structures):
   Generally, the design insulation covering shall be more than the diameter of the steel reinforcement and shall be set so that the requirement as to neutralization will be satisfied. However, with regard to the back face of the wall facing, the design insulation covering shall be set at 75 mm or more, to ensure that there will be no uneven faces in the sandbag section while considering that construction will be carried out without using back forms.
2) Minimum quantity of reinforcing steel rods (11.4.1 of the Design Standard for Concrete Structures):
   i) The quantity of reinforcing steel rods shall be such that the shrinkage and temperature-dependent crack of concrete will be kept down to an unharmful extent. Generally, arrangements shall be made so that the area of the reinforcing steel rods in the longitudinal direction is 0.15% or more of the entire area of concrete in any cross-

sections of the concrete member (11.4.1(1) of the Design Standard for Concrete Structures).

ii) The quantity of reinforcing steel rods shall be such that the concrete member will be prevented from breaking down in a fragile manner simultaneously with the occurrence of flexural cracks. Generally, steel reinforcing rods shall be so arranged that design bending yield proof stress M_{yd} will exceed crazing resistance M_{crd}. (11.4.1(2) of the Design Standard for Concrete Structures)

3) Maximum quantity of reinforcing steel rods (11.4.2 of the Design Standard for Concrete Structures):
The maximum quantity of the reinforcing steel rods shall be the quantity of the tensile reinforcement not causing brittle failure. Generally, the ratio of the tensile reinforcement shall be 75% or less of the ratio of the balanced reinforcement.

4) Restriction of stress intensity (11.5 of the Design Standard for Concrete Structures):
Stress intensity shall be restricted so that there will be no occurrence of excessive creep or strain or cracks in the axial direction due to compressive stress. Generally, the concrete bending compressive stress intensity shall be set to 40% or lower of design compressive strength.

5) Minimum spacing of reinforced concrete (11.6 of the Design Standard for Concrete Structures):
The minimum spacing of the reinforcing steel rods in the axial direction shall be 40 mm or more, and 4/3 times or more of the maximum dimension of the coarse aggregate, and 1.5 times or more the dimension of the reinforcing steel rods.

6) Arrangement of the reinforcing steel rods (13.5.4 of the Design Standard for Concrete Structures):

i) The total cross-sectional area of the reinforcing steel rods in the vertical direction in the RC wall facing that is subject to a vertical load shall be not less than 0.4% and not more than 4% of the total cross-sectional area of concrete (13.5.4(2)(a) of the Design Standard for Concrete Structures).

ii) The total cross-sectional area of the shear reinforcing steel rods in the vertical and horizontal directions in the RC wall facing that is subject to a vertical load shall be 0.15% or more of the total area of the concrete perpendicular to each direction (13.5.4(2)(b) of the Design Standard for Concrete Structures).

iii) The reinforcing steel rods in the vertical direction shall be 13 mm or more in diameter, and their arrangement spacing shall be not more than 2 times the thickness of the wall facing and 300 mm or less (13.5.4(2)(c) of the Design Standard for Concrete Structures).

iv) The reinforcing steel rods in the vertical direction that are arranged on both wall face sides of the wall facing shall be connected to each other with ties (13.5.4(2)(d) of the Design Standard for Concrete Structures).

v) The diameter of reinforcing steel rods in the horizontal direction shall be 13 mm or more and not less than 1/4 of the diameter of the reinforcing steel rods in the vertical direction, and their arrangement spacing shall be 300 mm or less.

7) Arrangement of the shear reinforcing steel rods (11.7.3 of the Design Standard for Concrete Structures):

i) Arrangement of the stirrups:

In any case where shear reinforcing steel rods are required according to calculations, the stirrups shall be arranged at such effective spacing that they will cross without fail the slant cracks that will occur in the web-section concrete. Generally, the spacing shall be not more than 1/2 of the effective height and not more than 400 mm.

In the case as well where shear reinforcing steel rods are not required according to calculations, the stirrups shall also be arranged at a spacing effective for controlling cracks that will occur due to the shrinkage of concrete, a temperature difference, etc. Generally, the spacing shall be not more than 3/4 of the effective height and not more than 300 mm.

ii) Arrangement of the bent-up bars:

The bent-up bars shall be arranged at a spacing and an angle that will be effective as shear reinforcing steel rods against slant cracks. Generally, the spacing shall be not more than 1.5 times the effective height, and its angle to the axis member shall bee 30° or larger.

8) Bent form of reinforcing steel rods (11.8 of the Design Standard for Concrete Structures):

The inner bend radius of the bent-up bars shall be not less than 5 times the reinforcing steel bar diameter Φ.

9) Fixation of the reinforcing steel bar in the axial direction (11.9.4 of the Design Standard for Concrete Structures):

In the case of fixing the reinforcing steel bar in the axial direction to the concrete on the compression side by using deformed steel rods for bent-up bars, the fixation length shall be not less than 15Φ (Φ is the diameter of steel rod) if any standard hooks are not used (11.9.4.1(3)(a)(ii) of the Design Standard for Concrete Structures).

10) Standard hooks for the reinforcing steel rods in the axial direction (11.9.4.3 of the Design Standard for Concrete Structures):

The inner bend radius r of the standard hooks of the reinforcing steel rods in the axial direction shall be not less than the value shown in 11.9.1 of the Design Standard for Concrete Structures.

11) Standard hooks of the shear reinforcing steel rods (11.9.5.2 of the Design Standard for Concrete Structures):

The inner bend radius r of the standard hooks of the shear reinforcing steel rods shall be not less than the value shown in 11.9.2 of the Design Standard for Concrete Structures.

With regard to (5) above:

In the RC wall facing constructed by the RRR-B Construction Method, expandable joints using a joint material shall be installed at intervals of 20 m or less. Furthermore, on the outer face of the wall facing, shrinkable joints having V-shaped notches shall be installed at intervals of 5 m or so.

However, particularly in any case where the ground subsides to an extreme extent or in any location where extreme temperature changes occur, the intervals of the expandable joints shall be shorter (Fig. 2.5.1-5).

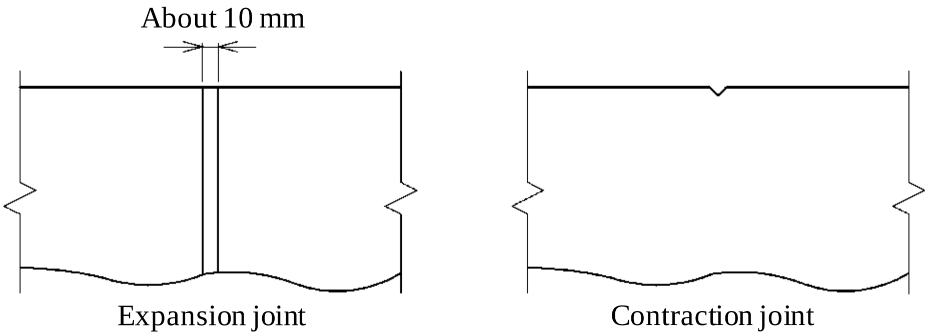


Figure 2.5.1-5 Joints in facing

With regard to (6) above:

The main functions that are expected of the temporary holding at the wall face are as follows:

1) Since the wall face is near-vertical or vertical, the temporary holding serves to ensure the stability of the backfill at the time of construction, preventing the backfill material from being pushed out from the wall, among other things.
2) The temporary holding functions also as a vertical drain layer after the completion of the wall.
3) The temporary holding plays a role as a buffer material between the facing having high stiffness and the backfill section having much lower stiffness than the facing.
4) The temporary holding absorbs differential settlement between the RC facing and the backfill.

Under the present circumstances, either sandbags or welded wire mesh is used for the temporary holding.

Sandbags have long been used for GRS RWs (Refer to Fig. 2.5.1-6 (a)). They exhibit good workability in relation to changes in the dimensions of the backfill zone and excellent follow-up properties for the deformation of the backfill after construction. However, it has been pointed out that, in any case where the scale of construction is large, for example, sandbags are inferior in workability in fabrication and installation.

As for the bag material used for sandbags, those rough bags which show good water permeability shall be used because they are expected to serve as a drain layer after the completion of the wall as shown in 2) above. (Refer to the Materials Manual.)

Welded wire mesh has good workability, and it has been confirmed by tests that the use of proper welded wire mesh (refer to Fig. 2.5.1-6 (b) and (c)) will fully satisfy the requirements for strength and deformation properties as the temporary holding in use.

Generally, in any case where the scale of construction work is large to some extent, where the construction site is large, or where the foundation ground has few undulations and are relatively flat, and where any significant differential settlement will not occur during construction work, among other cases, it is considered that the use of welded wire mesh exhibits higher workability and economic performance than sandbags. However, in any case where the construction site is small and it is impossible to bring a large quantity of materials for temporary holding into the site or where the retained natural ground has many significant undulations, it is difficult to use welded wire mesh. If welded wire mesh is to be employed, the standard type shown in Fig. 2.5.1-6 (b) shall be used. However, in the case where it is difficult to obtain such standard type owing to the local conditions at the site, economics should be studied fully, and the regular welded wire mesh type shown in Fig. 2.5.1-6 (c) may be used.

As to the question of which of the two should be used for the temporary holding at the wall face, sandbags or welded wire mesh, it is important to fully study the construction conditions at the site and select the proper method. Furthermore, depending on the local construction conditions, etc., it might be appropriate to use both sandbags and welded wire mesh in some cases.

Further, as for the form of the winding part of geotextile, a width of 300mm or more needs to be ensured for the top width of the sandbags and the top width of the crusher run as a drain layer.

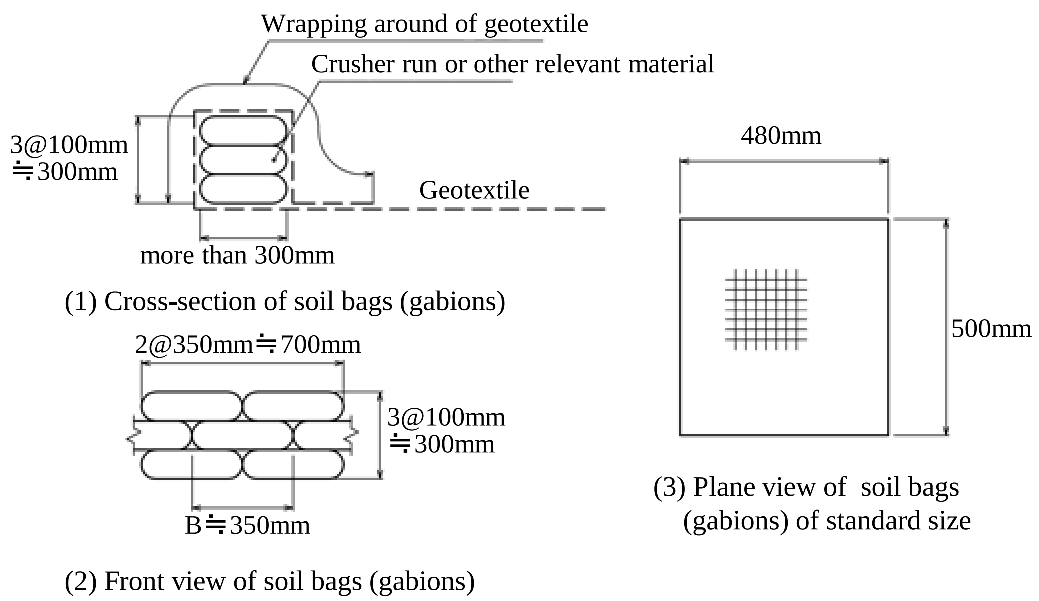


Figure 2.5.1-6 (a) Temporary earth retaining by sandbags

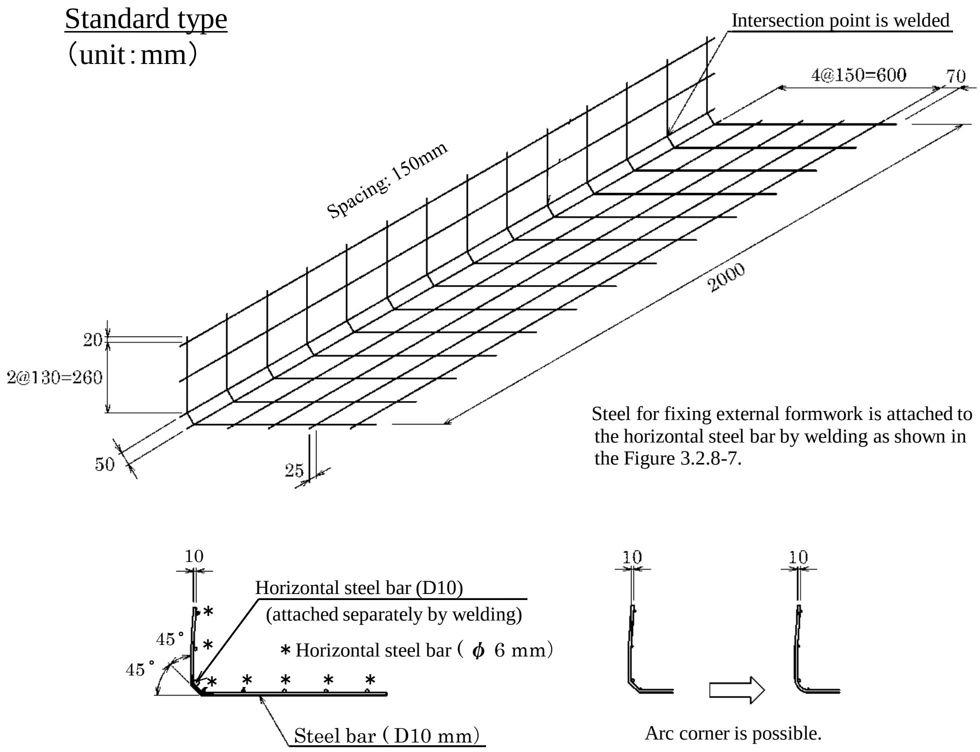


Figure 2.5.1-6 (b) Temporary earth retaining by welded steel fabrics (standard type for GRS RW)

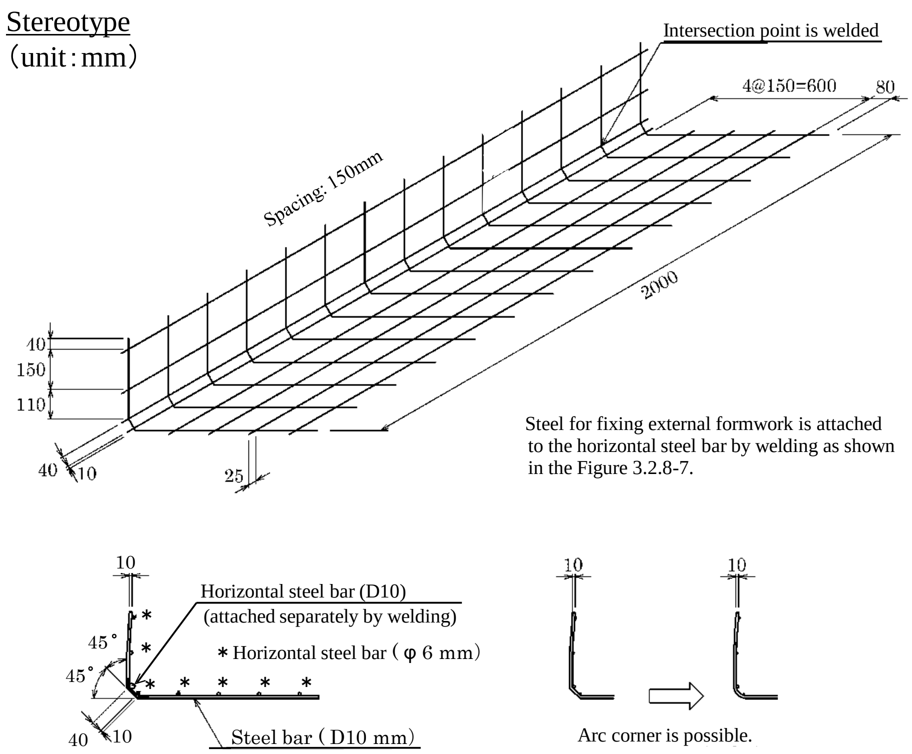


Figure 2.5.1-6 (c) Temporary earth retaining by welded steel fabrics (when using a usual type available in the market)

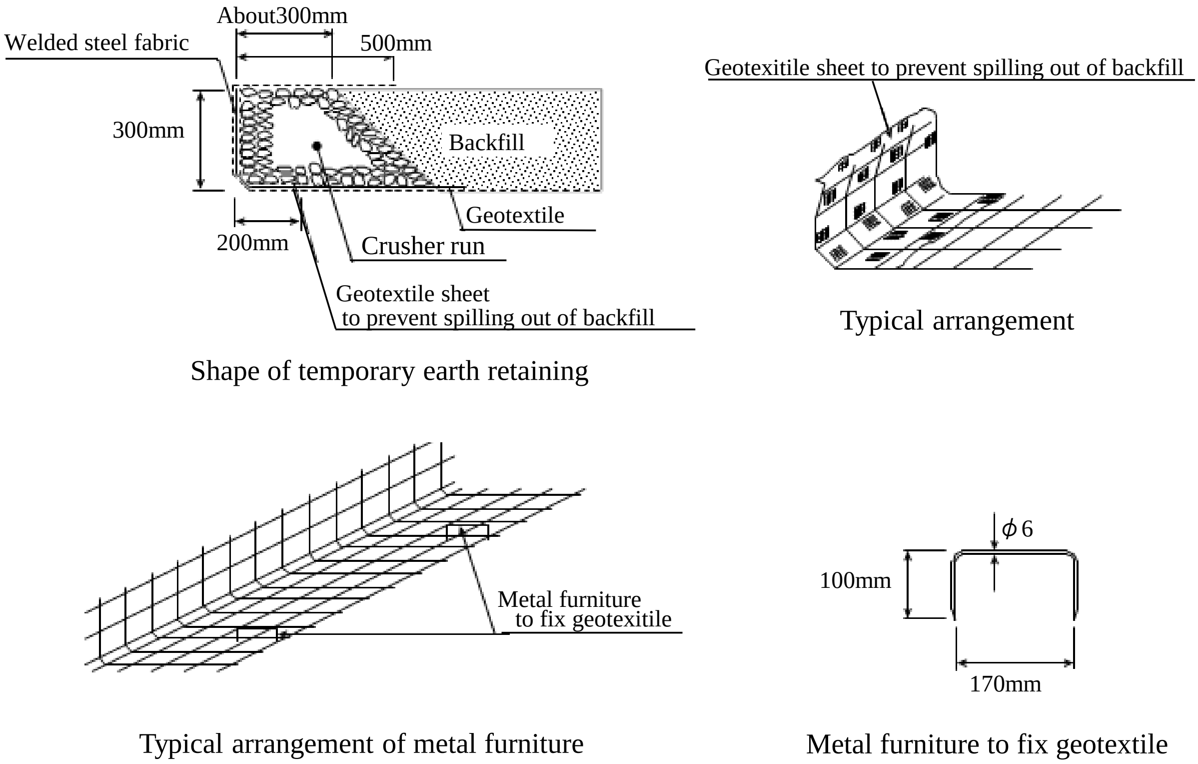


Fig. 2.5.1-6 (d) Temporary earth retaining by welded steel fabrics

With regard to (7) above:

With the GRS RW, a drain layer using crusher run, etc. shall be provided on the back of the RC wall facing, and a drain pipe shall be installed at intervals of one location for every 2.0 – 4.0 m^2 or so. With the GRS RW, sandbags or welded wire mesh is used as a temporary holding as described in (6) above at the time of construction (Fig. 2.5.1-8). In this case, however, a drain layer shall be set up by putting a material having good permeability (crusher run, for example) in the sandbags in advance or placing a gravel material on the welded wire mesh.

If the GRS RW is constructed by using cohesive soil as the backfill material, it is preferable that a geotextile having an additional function of drain be used. The basic principle is that it is preferable that a geotextile having an additional function of drain be adopted for all the reinforcement layers. If such adoption is difficult, it is also possible to make a study and use a grid material (i.e., a geogrid) and a composite material (i.e., a sheet of woven geotextile sandwiched between two sheets of non-woven geotextile) together.

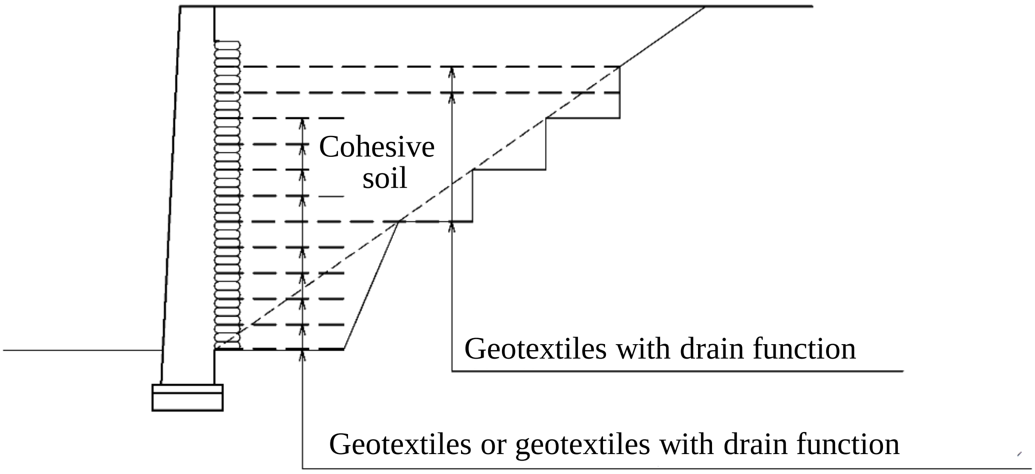


Fig. 2.5.1-7　Cross-section of RRR-B in case of cohesive soil embankment

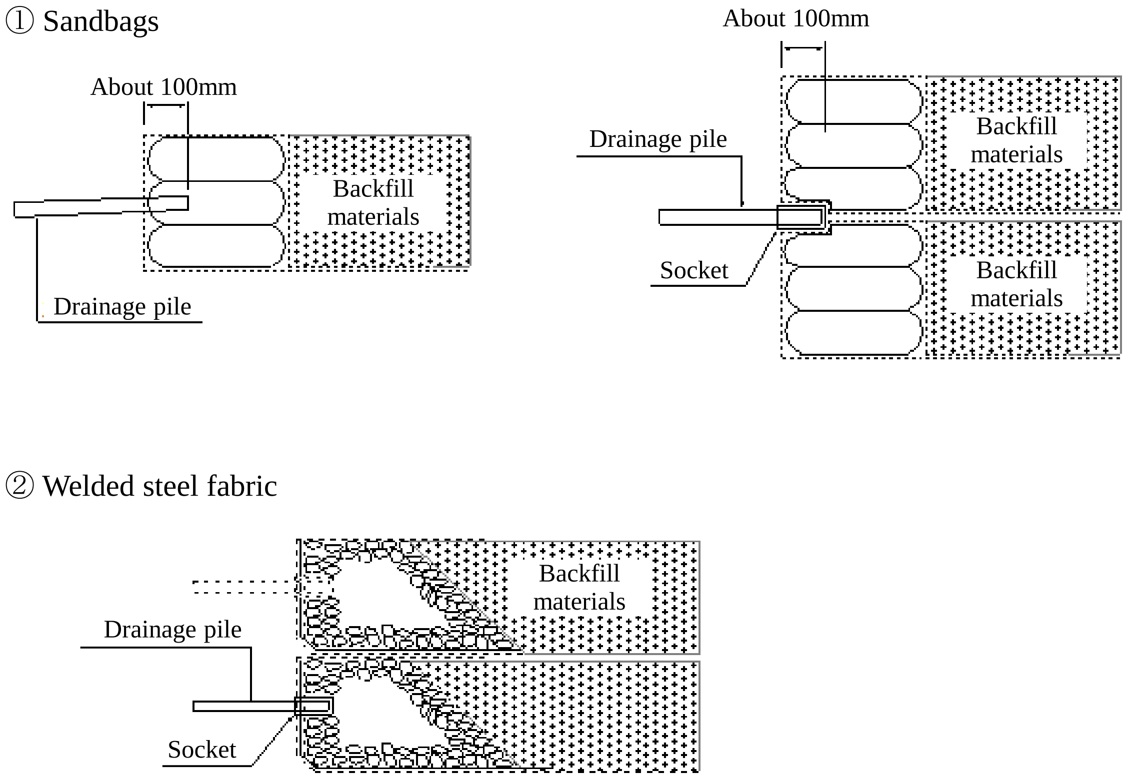


Fig. 2.5.1-8　Typical arrangement of drain pipe at the back face of the wall facing

With regard to (8) above

Geotextile sheets at an outward-bent corner and an inward-bent corner should be arranged with overlapping of design length part of the geotextile sheets as shown in Figure 2.5.1-9 and Figure 2.5.1-10 respectively.

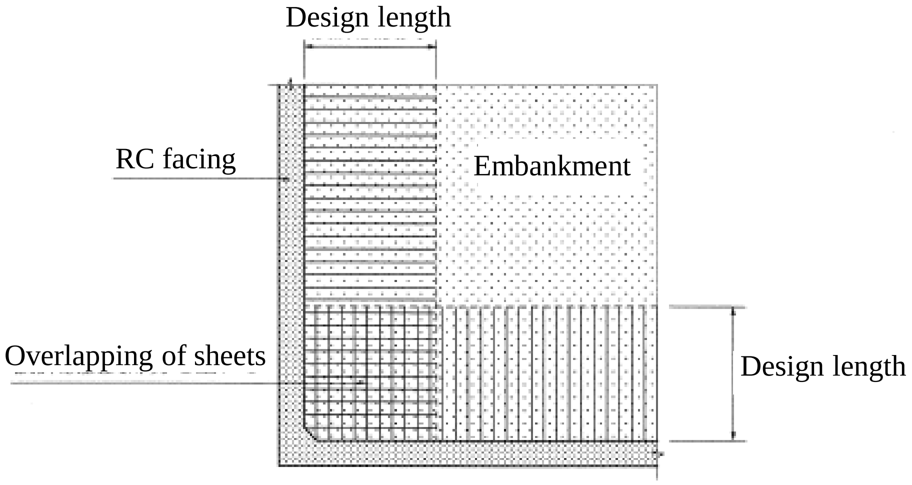


Fig. 2.5.1-9 Arrangement of geotextile sheets at an outward-bent corner

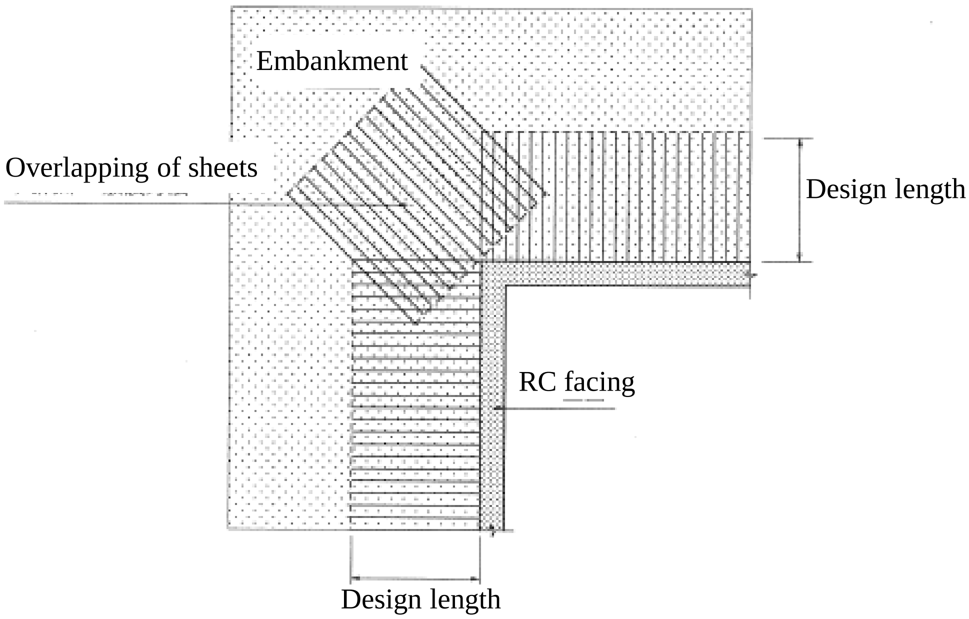


Fig. 2.5.1-10 Arrangement of geotextile sheets at an inward-bent corner

2.6 Technique and Modeling for Verification of Satisfactory Performance

2.6.1 Verification of Satisfactory Performance in Relation to Internal Stability

In the evaluation of the internal stability of the geosynthetic-reinforced soil retaining wall (GRS RW), stability against sliding and overturning shall be separately evaluated, and the design response values shall be calculated by the two-part wedge method.

[Commentary]

(1) Procedure of verification:

A detailed examination of internal stability shall be conducted for slip stability and overturning stability by using the two-part wedge method (the limit equilibrium stability analysis by the trial wedge method using two wedges separated by straight failure planes) in accordance with 8.3.5.2 of the Design Standard for Earth Retaining Structures, and calculation shall be made repeatedly by the procedure set forth in Fig. 2.6.1-1.

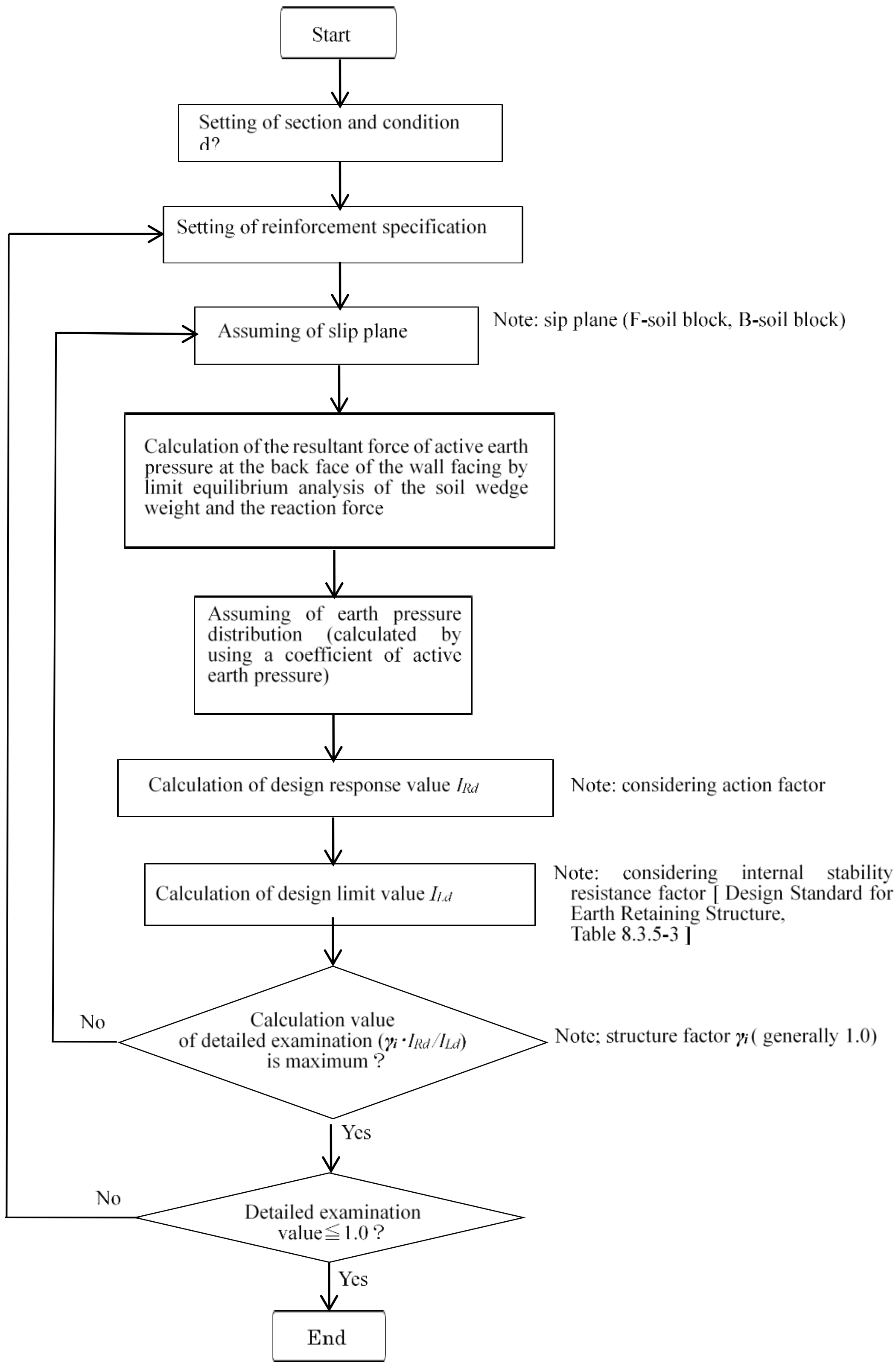
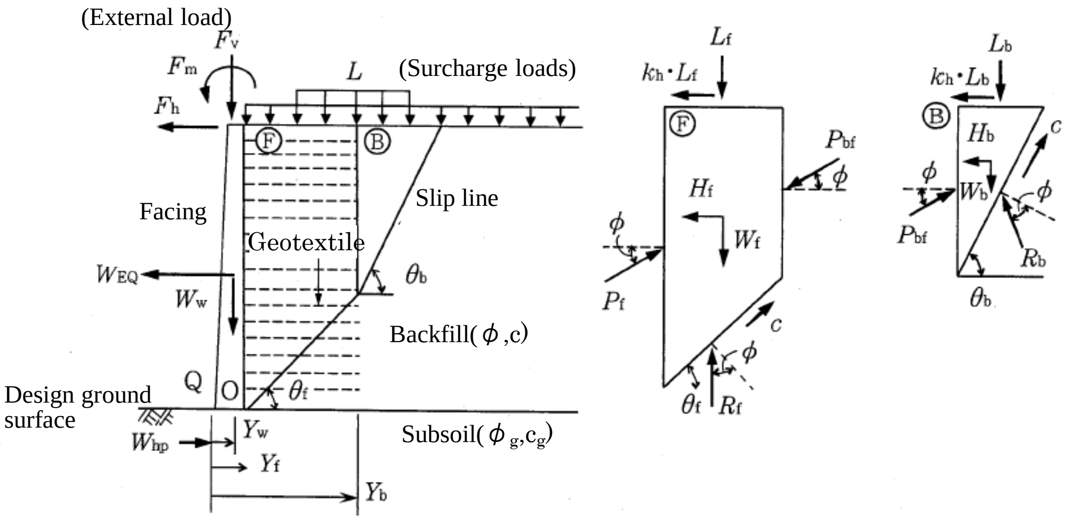


Figure 2.6.1-1 Detailed examination flow of the internal stability

(2) Two-part wedge method (the limit equilibrium stability analysis by the trial wedge method using two wedges separated by two straight failure planes):

1) Force equilibrium based on the two-part wedge method:

Fig. 2.6.1-2 shows a limit equilibrium of forces based on the two-part wedge method. In calculating the active earth pressure acting on the back face of the RC facing of the GRS RW, it shall be assumed that these forces are at the limit equilibrium state. Under this condition, the active earth pressure shall be calculated as reaction force along the sliding plane for the block on the retained backfill (Block B) and the block in the reinforced zone of the facing side (Block F) by the equation for the limit equilibrium state for respective forces. For the limit equilibrium equation for the forces, refer to 4.4.2.1, Earth Pressure as Permanent Action, of the Design Standard for Earth Retaining Structures.



where W: Weight of soil wedge (kN/m)
k_h : Lateral seismic coefficient
R: Reaction force acting the soil wedge (kN/m)
c: Cohesion of soil (kN/m^2)
H: Seismic inertia force of the soil wedge (kN/m)
L: Surcharge load acting on the soil wedge (kN/m^2)
P: Total resultant earth pressure (kN/m)
ϕ : Internal friction angle of soil (°)

Fig. 2.6.1-2 Schematic diagram of two-wedge method
(Outline of analysis of internal stability of "Reinforced-backfill retaining walls")
[Design Standard for Earth Retaining Structures, Figure 8.3.4-3]

2) Earth pressure intensity and earth pressure distribution (7.6.3, Earth Reinforcement Design Calculation System – Design RRR ver 3.1C, of the Design Standard for Earth Structures): To conduct a analysis of earth pressure, it becomes necessary to consider not only the magnitude of force but also the location in which the resultant force of earth pressure acts. For this reason, in this Manual, the location in which the resultant force of earth pressure is determined by assuming a pattern of distribution of earth pressure for each external force.
   (a) Assumption of a distribution pattern of earth pressure:
   The distribution of earth pressure shall be assumed as follows (refer to Fig. 2.6.1-3)
      i. Earth pressure due to the dead weight of the retained backfill will act on the back face of the RC facing as a triangle earth pressure distribution pattern.

ii. Earth pressure due to a vertical surcharge load will spread at an angle α＝30° in the vertical direct in and will act on the back face of the RC facing as a uniform earth pressure distribution form.

iii. A horizontal surcharge load (inertial force of an earthquake) will act on the back face of the RC facing as earth pressure of inverted-triangle distribution pattern.

iv. The sum of those resultant earth pressure components will be equal to the value determined by the two-part wedge method, P_F.

$$P_F = \frac{1}{2} K_W \cdot \gamma \cdot H^2 + K_W \cdot p \cdot b + q \cdot b \qquad \text{(Equation 2.6.1-1)}$$

Therefore, from equation 2.6.1-1, the coefficient of active earth pressure, K_w, that is used for a GRS RW can be determined by the equation 2.6.1-2.

$$K_W = \frac{P_F - q \cdot b}{\gamma \cdot \frac{H^2}{2} + p \cdot b} \qquad \text{(Equation 2.6.1-2)}$$

where P_F : Total resultant earth pressure acting on the RC facing determined by the two-wedge method (kN/m)

γ : Unit weight of soil (kN/m^2)

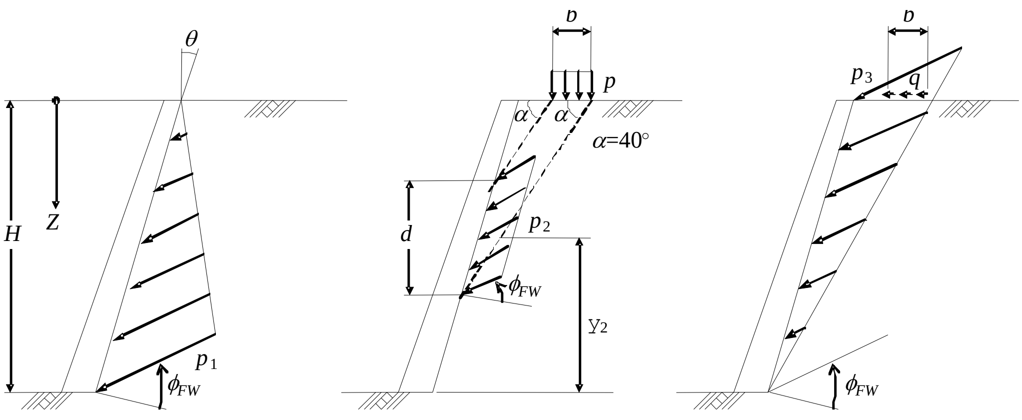
p : Vertical surcharge load (kN/m^2)

q : Horizontal surcharge load （$q = k_h \cdot p$） (kN/m^2)

b : Width of vertical surcharge load on the crest of the backfill (i.e., on the crest of two wedges) (m)

k_h : Lateral seismic coefficient

H : Height of wall (m)



$p_1 = K_W \cdot \gamma \cdot H \cos\theta$ $\qquad$ $p_2 = K_W \cdot p \cdot \frac{b}{d} \cos\theta$ $\qquad$ $p_3 = \frac{2q \cdot b \cos\theta}{H}$

(a) Backfill self weight $\qquad$ (b) Vertical surcharge load $\qquad$ (c) Horizontal surcharge load

Fig. 2.6.1-3 Assumed earth pressure distributions

［Design Standard for Earth Retaining Structures, Figure 4.4.8］

(b) Earth pressure due to the dead weight of retained backfill

$$p_1 = K_W \cdot \gamma \cdot Z cos\theta \qquad \text{(Equation 2.6.1-3)}$$

where Z : Vertical depth from the top of the facing (m)

θ : Angle between the back face of the facing and the vertical (°)

(c) Earth pressure due to uniformly distributed vertical surcharge load:

$$p_2 = \frac{1}{2} K_W \cdot p \cdot \frac{b}{d} cos\theta \qquad \text{(Equation 2.6.1-4)}$$

(d) Earth pressure due to uniformly distributed horizontal surcharge load:

$$p_3 = \frac{2(H-Z)}{H^2} \cdot q \cdot b\ cos\theta \qquad \text{(Equation 2.6.1-5)}$$

Further, the direction of the acting of these earth pressures shall incline in the upward direction by the friction angle ϕ_{FW} from the direction normal to the back face of the facing.

(e) Location at which the resultant earth pressure acts:

The location at which the resultant earth pressure acts shall be determined by equation 2.6.1-6.

$$y_P = \frac{T_{p1} \cdot (H/3) + T_{p2} . y_2 + T_{p3} \cdot y_3 \cdot (2H/3)}{P_F} \qquad \text{(Equation 2.6.1-6)}$$

where: y_p: Location height of the total resultant earth pressure force (m)

y_2: Location height of the resultant earth pressure due to vertical surcharge load (m)

T_{p1}: Resultant earth pressure force due to self-weight of retained backfill (kN/m)

$$T_{p1} = \frac{1}{2} K_W \cdot \gamma \cdot H^2 \qquad \text{(Equation 2.6.1-7)}$$

T_{p2}: Resultant earth pressure forces due to uniformly distributed vertical surcharge load (kN/m)

$$T_{p2} = K_W \cdot p \cdot b \qquad \text{(Equation 2.6.1-8)}$$

T_{p3}: Resultant earth pressure forces due to uniformly distributed horizontal surcharge load (kN/m)

$$T_{p3} = k_h \cdot q \cdot b \qquad \text{(Equation 2.6.1-9)}$$

(3) Detailed examination method for lateral sliding stability:

A detailed examination of lateral sliding stability is performed by studying the limit equilibrium of horizontal forces that act on the RC facing. It shall be conducted as follows:

1) Detailed sliding stability examination equation:

A detailed examination of sliding stability shall be conducted by Equation 2.6.1-10.

$$\gamma_i \cdot \frac{H_{Rd}}{H_{Ld}} \leqq 1.0 \qquad \text{(Equation 2.6.1-10)}$$

where γ_i : Structure coefficient (set as 1.0, in general)

H_{Rd}: Design lateral sliding force (kN/m)

H_{Ld}: Design lateral sliding resistance force (kN/m)

$$H_{Rd} = \gamma_{fh} \cdot P_{fh} + \gamma_{EQ} \cdot W_{EQ} + \gamma_{EQ} \cdot WT_{EQ} + \gamma_W \cdot W + \gamma_{WT} \cdot WT \qquad \text{(Equation 2.6.1-11)}$$

where P_{fh}: Horizontal component of resultant earth pressure force ($=P_f \cdot \cos\theta$) (kN/m)

W_{EQ} : Seismic inertia force of the facing (kN/m)

WT_{EQ}: Seismic inertia force of the top of facing by noise barrier, electric pole etc. (kN/m)

W : Wind load (outside direction) (kN/m)

γ_n : Each action factor (Table 2.3.3-1)

WT : Horizontal permanent force at the top of facing by electric pole etc. (kN/m)

$$H_{Ld} = f_{ri} \cdot (\sum T_i + \gamma_W \cdot W + \gamma_{WT} \cdot W_T + \gamma_{Wbs} \cdot W_{bs}) \qquad \text{(Equation 2.6.1-12)}$$

where f_{ri} : Internal stability resistance factor (according to Table 2.6.1-1)

T_i : Reinforcement horizontal resistance force in the layer i (kN/m)

W : Wind load (inside direction) (kN/m)

W_{bs} : Shear resistance at the base of the facing foundation (kN/m)

γ_n : Each action factor (Table 2.3.3-1)

Table 2.6.1-1 Internal stability resistance factor f_{ri}

[Design Standard for Earth Retaining Structure, Table 8.3.5-3, Table 8.3.5-6]

	Main actions	Internal stability resistance factor f_{ri}
Safety	Permanent actions	0.50
	Variable actions	0.67
	Seismic action (Level 1 seismic ground motion)	0.80
Restorability	Seismic action (Level 2 seismic ground motion)	1.00

Here, the method for calculating the horizontal resistance of the geotextile shall be by Equation 2.6.1-13, and the horizontal resistance of the geotextile shall be whichever is smaller, the design tensile strength, T_d, of the geotextile or the resistance, T_p, of the geotextile to pull-out from the stable backfill.

$$T_i = \min(T_p, T_d) \qquad \text{(Equation 2.6.1-13)}$$

where T_d : Design tensile rupture strength of the geotextile (kN/m)
T_p : Pullout resistance in the backfill behind the respective trial failure planes (kN/m) (obtained by Equation 2.6.1-14)
F_{rg} : Resistance modulus related to the pullout failure of the reinforcement (Table 2.6.1-2)

$$T_p = f_{rg}\,(\sigma_{vi} \cdot \tan\Phi \cdot 2l_i + c \cdot l_i) \qquad \text{(Equation 2.6.1-14)}$$

where l_i : Anchorage length of geotextile layer i (m)
σ_{vi} : Effective vertical stress acting on geotextile layer i (kN/m^2)
Φ, c : Internal friction angle (°) and cohesion of the backfill material (kN/m^2)

Table 2.6.1-2 Resistance factor related to the pullout failure of the reinforcement f_{rg}
[Design Standard for Earth Retaining Structure, Table 8.3.5-3, Table 8.3.5-6]

	Main actions	Resistance factor related to the pullout failure of the reinforcement f_{rg}
Safety	Permanent actions	0.50
	Variable actions	0.67
	Seismic action (Level 1 seismic ground motion)	0.80
Restorability	Seismic action (Level 2 seismic ground motion)	1.00

Also, the shear resistance, W_{bs}, of the ground at the base of the facing foundation shall be calculated by the Equation 2.6.1-15.

$$W_{bs} = f_{rbs} \cdot (W_v \cdot \tan\Phi_g + c_g \cdot b) \qquad \text{(Equation 2.6.1-15)}$$

where W_v : Total vertical load acting on the base of the facing foundation (kN/m)
Φ_g : Internal friction angle of the supporting ground (°)
c_g : Cohesion of supporting ground (kN/m^2)
b : Width of the facing foundation (m)
f_{rbs} : Coefficient of friction between the base of the facing foundation and the supporting ground (in general, 1.0 for sandy soil (i.e., soil class 1-3) and 0.5 for cohesive soil (i.e., soil class 4))

However, W_v shall be upper-limited by the design vertical bearing capacity, R_{vd}, that is prescribed in the Design Standard for Foundation Structures. In this case, the embedment depth effect at the bottom of the facing foundation shall not be taken into consideration in the determination of R_{vd}.

(4) Detailed examination of overturning stability:

A detailed examination of overturning stability is performed by studying a limit equilibrium of the moment by taking the toe of the facing as the rotation center. It shall be conducted as follows:

(a) Detailed overturning stability examination equation:

A detailed examination of overturning stability shall be conducted Equation 2.6.1-16.

$$y_i \cdot \frac{M_{Rd}}{M_{Ld}} \leqq 1.0 \qquad \text{(Equation 2.6.1-16)}$$

where y_i : Structure coefficient (1.0, in general)

M_{Rd} : Design overturning moment (kN·m/m)

M_{Ld} : Design overturning resistance moment (kN·m/m)

$$M_{Rd} = \gamma_{Pf} \cdot M_{Pf} + \gamma_{WT} \cdot M_{WT} + \gamma_{EQ} \cdot M_{WEQ} + \gamma_{EQ} \cdot M_{WTEQ} + \gamma_{Wi} \cdot M_{Wi} + \gamma_{WT2} \cdot M_{WT2}$$

(Equation 2.6.1-17)

where M_{Pf} : Moment by earth pressure resultant force (kN·m/m)

M_{WT} : Moment by the self weight of outside electric pole (kN·m/m)

M_{WEQ} : Moment by the seismic inertia force of the facing (kN·m/m)

M_{WTEQ} : Moment by the seismic inertia force acting on the crest of the facing (kN·m/m)

M_{Wi} : Moment by the wind load (outward direction) (kN·m/m)

M_{WT2} : Moment by the force acting on the crest of the facing by electric pole etc. (outward direction) (kN·m/m)

γ_n : Each action factor (Table 2.3.3-1)

$$M_{Ld} = f_{ri} \cdot (\Sigma M_{rg} + \gamma_{WT} \cdot M_{WT} + \gamma_w \cdot M_w + \gamma_{Wi} \cdot M_{Wi} + \gamma_{WTM} \cdot M_{WTM} + \gamma_{PfV} \cdot M_{PfV} + \gamma_{PbV} \cdot M_{PbV}$$

(Equation 2.6.1-18)

where f_{ri} : Internal stability resistance factor (Table 2.6.1-1)

M_{rg} : Resistance moment by the geotextile layers (kN·m/m)

M_{WT} : Moment by the self weight of the inside part of the electric pole (kN·m/m)

M_W : Moment by the self weight of the facing (kN·m/m)

M_{Wi} : Moment by the wind load (inward direction) (kN·m/m)

M_{WTM} : Moment by the force acting on the crest of the facing by electric pole etc. (inward direction) (kN·m/m)

M_{PfV} : Moment by [the vertical component of the resultant force acting on the back of the facing p_f minus the vertical component of the resultant force acting at the back of Block Ⓕ p_{bf}], defined as the effective vertical component p_f (p_f, p_{bf} : see Block Ⓕ in Figure 2.6.1-2) (kN·m/m)

M_{PbV} : Moment by vertical component of the resultant force P_{bf} (P_{bf} : see Block Ⓕ in Figure 2.6.1-2) (kN·m/m)

γ_n : Each action factor according to each resistance element

Here, the resistance moment of each geotextile layer is obtained by multiplying the geotextile tensile force by the distance from the center of rotation.

2.6.2 Verification of Satisfactory Performance in Relation to External Stability

In principle, the satisfactory external stability shall be verified by using a method which has been validated in advance. In the case of applying such examination to the GRS RW that is handled in this Manual, a study shall be generally carried out by the modified Fellenius method.

[Commentary]

A study of the external stability of the GRS RW refers to a detailed examination conducted as to whether or not the entire system including the GRS RW and the supporting ground has a specified level of safety. The study may be made by using the modified Fellenius method. Its details shall be as set forth in the Design Standard for Earth Structures.

In this case, the location of the sliding plane shall be below the embedded depth of the foundation for the facing.

At the time of conducting a detailed examination of external stability, if the sliding plane crosses the long reinforcement layer, the anchorage effect of the reinforcement shall be taken into account as shown in Fig. 2.6.2-1.

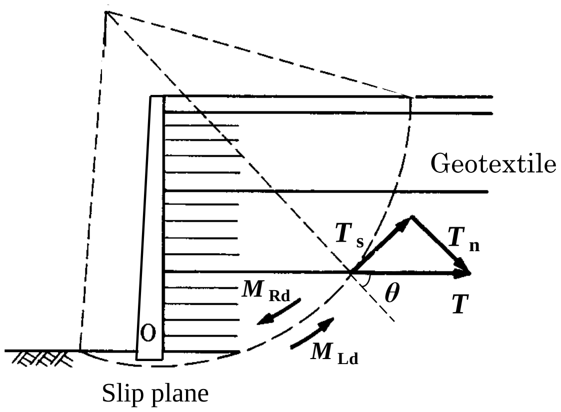


Figure 2.6.2-1 External stability of GRS RW

［Design Standard for Earth Retaining Structures, Figure 8.3.5-1］

The stability against circular sliding is evaluated by Equation (2.6.2-1).

$$y_i \cdot \frac{M_{Rd}}{M_{Ld}} = y_i \cdot \left\{ \frac{r\Sigma(W_i \cdot \sin\Theta_i)}{(f_{rs} \cdot \Sigma\tau_s) \cdot r + f_{rs}\Sigma(T_i \cdot \cos\alpha_i \cdot r + T_i \cdot \sin\alpha_i \cdot \tan\Phi \cdot r)} \right\} \leqq 1.0 \qquad \text{(Equation 2.6.2-1)}$$

where y_i : Structure coefficient (1.0, in general)

M_{Rd} : Design driving moment (kN·m/m)

M_{Ld} : Design resistance moment (kN·m/m)

$\Sigma\tau_s$: Total of the shear resistance force of soil along the slip plane

r : Radius of the circular slip plane (m)

T_i : Reinforcement resistance tensile force in the layer i (kN/m)

l_i : Anchorage length of geotextile layer i (m)

f_{rs} : Rotational sliding resistance factor (Table 2.6.2-1)

α_i : Angle between the geosynthetic layer i and the circular slip plane at the intersection (^{o})

Φ : Internal friction angle of the backfill material

Θ_i : Angle between the radius extended to the center at the base of slice i and the vertical line

W_i : Weight of the soil slice i per unit width (kN/m)

Table 2.6.2-1 Rotational sliding resistance factor f_{rs}

[Design Standard for Earth Retaining Structure, Table 8.3.5-4]

	Main actions	Rotational sliding resistance factor f_{rs}		
		Performance rank I	Performance rank Ⅱ	Performance rank Ⅲ
Safety	Self weight	0.83	0.83	0.91
	Self weight+train load	0.71	0.76	0.76
	Level 1 seismic ground motion	0.83	0.91	1.00

2.6.3 Method of Verification of Satisfactory Performance based on Residual Displacement

A study of the restorability of the GRS RW shall be made (1) by Equation (2.6.3-1) by calculating the design response values with respect to the RC facing, damage of the reinforcement and residual displacement of the supporting ground and the reinforced soil in accordance with 8.3.4 of the Design Standard for Earth Retaining Structures and (2) by setting design limits taking account of the restorability of the GRS RW.

[Commentary]

For the restorability of the GRS RW, a detailed performance examination shall be conducted by calculating the following three types of residual displacement and deformation:

i. Amount of settlement due to the residual displacement by sliding and, overturning and shear deformation of the reinforced soil
ii. Amount of the shaking-down settlement of the reinforced soil
iii. Amount of the shaking-down settlement of the supporting ground

With respect to i. "Amount of settlement due to the residual displacement by sliding, overturning and shear deformation of the reinforced soil" shall be determined by calculating the magnitude of each individual residual displacement and deformation by sliding, overturning and shear deformation. Then, the amount of settlement is calculated by using the sum of horizontal displacements by the three modes while by assuming that the same volume as the one caused by the total horizontal displacement will occur by uniform settlement within the range of sliding plane as shown in Fig. 2.6.3-1.

With regard to ii. "Amount of the shaking-down settlement of the reinforced soil", a detailed examination of the amount may be omitted on the assumption that the retained backfill material will meet the requirements for the degree of compaction of the backfill and compaction management method for each performance rank that are shown in 3.2, Construction of Embankments, of the Design Standard for Earth Structures.

Moreover, as for iii. "Amount of the shaking-down settlement of the ground", a detailed examination of the amount may be omitted on the assumption that the supporting ground conditions of the GRS RW will meet the requirement for each performance rank that are shown in 3.1.6, Supporting Ground Conditions of Embankments, of the Design Standard for Earth Structures.

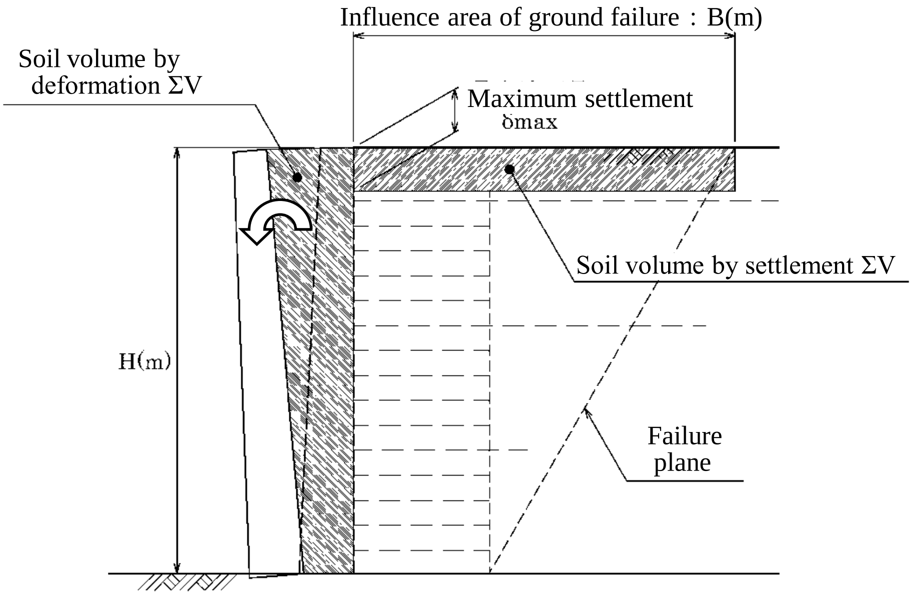


Figure 2.6.3-1 Schematic diagram of calculation method of settlement in the retained backfill

Equation of detailed examination $\quad y_i \cdot \frac{\delta_{Rd}}{\delta_{Ld}} \leqq 1.0 \quad$ (Equation 2.6.3-1)

where y_i : Structure coefficient (set as 1.0, in general)

δ_{Rd} : Response value of settlement (mm)

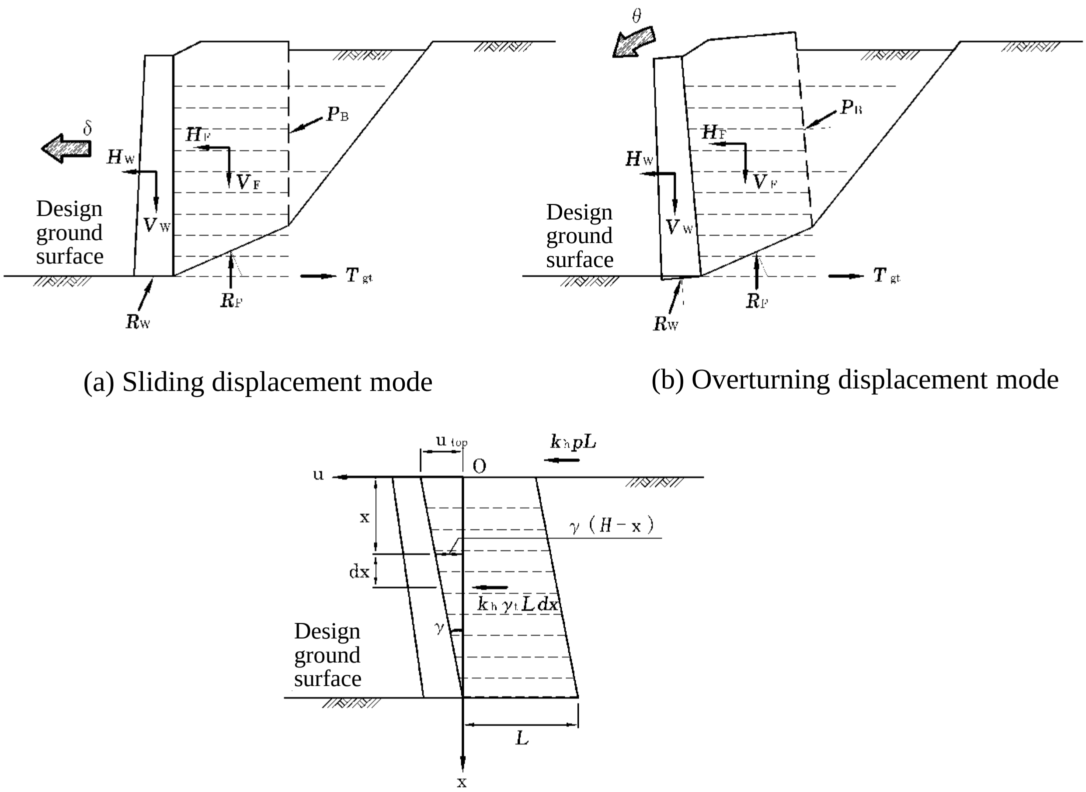
δ_{Ld} : Limit value of settlement (mm)

(1) Method for calculating the residual displacement and deformation of the reinforced soil:

1) Yield seismic intensity for each displacement mode:

As stated above, the displacement and deformation of the reinforced backfill of GRS RW shall be calculated in three types of displacement and deformation mode (sliding, overturning and shear deformation) (Fig. 2.6.3-2). It has been demonstrated by the results of previous model tests that deformation in the shear mode begins to occur earliest of the three displacement modes.

From this observation, in the calculation of the residual displacement and deformation by Level 2 design seismic loads, the yield seismic intensity in the shear deformation mode (i.e., seismic intensity occurring on the primary slide plane, k_y) shall be calculated by Equation 2.6.3-2, and then the yield seismic intensity in the overturning and slide modes shall be calculated by using the sliding that occurs at that time of the start of shear deformation yielding. Equation 2.6.3-2 is an empirical equation derived from the results of model tests (Horii et. al., 1998)



(a) Sliding displacement mode (b) Overturning displacement mode

(c) Shear deformation mode

Fig. 2.6.3-2 Three displacement and deformation modes of "GRS RWs"

[Design Standard for Earth Retaining Structures, Figure 8.3.4-4]

$$K_y = \frac{\bar{L}}{2H} \qquad \text{(Equation 2.6.3-2)}$$

where k_y : Yield seismic intensity in shear deformation mode

$\bar{L}$: Average width of reinforced region

H : Height of embankment

(Ref.: Horii, K., Tateyama, M., Koseki, J. and Tatsuoka, F. "Stability and Residual Deformation Analysis of Geosynthetic Reinforced Earth Retaining Wall with Rigid Facing due to Large Earthquakes" Geosynthetics Engineering Journal, IGS Japan Chapter; Vol. 13, December, 1998)

2) Method for calculating yield seismic intensity in each displacement/deformation mode:
Yield seismic intensity in the sliding and overturning modes to be used for the Newmark method shall be calculated. Yield seismic intensity shall be calculated by conducting a detailed stability examination in each displacement/deformation mode. Further, in the calculation of yield seismic intensity, unlike 2.6.1 (Detailed Performance Examination in Relation to Internal Stability), a detailed stability examination shall be conducted by assuming that for the whole of GRS RW having a RC facing that is integrated to the

reinforced backfill zone to evaluate for the earth pressure by the trial two-wedge method.

i. Calculation of yield seismic intensity in the sliding mode:

The calculation of yield seismic intensity in the sliding mode shall be made from an equilibrium of the horizontal force that acts on the RC facing and block Ⓕ.

$$y_i \cdot \frac{H_{Rd}}{H_{Ld}} \leqq 1.0 \qquad \text{(Equation 2.6.3-3)}$$

where y_i : Structure coefficient (set as 1.0, in general)

H_{Rd} : Design sliding force (kN/m)

H_{Ld} : Design sliding resistance force (kN/m)

$H_{\mathrm{Rd}} = H_W + H_F + F_{px} + P_B \cdot \cos(\delta_B - \alpha)$

$H_{Ld} = R_{WX} + R_F \cdot \sin(\Phi - \zeta_F) + \Sigma T_{gt} \cdot \cos\beta$

where R_{WX} : Horizontal resistance force acting on the base of the RC facing (kN/m)

R_F : Reaction force acting on the base of Block Ⓕ (kN/m)

Φ : Internal angle of friction (i.e., peak friction angle) of the backfill

T_{gt} : Strength of reinforcement (kN/m)

H_W : Horizontal inertia force of the RC facing (kN/m)

H_F : Horizontal inertia force of Block Ⓕ (kN/m)

F_{px} : Horizontal load acting on the crest of the facing (horizontal electric pole load) (kN/m)

P_B : Earth pressure acting on the back of Block Ⓕ (kN/m)

α : Angle of the back face of the facing counterclockwise from the vertical direction (°)

ζ_F : Angle of the base of Block Ⓕ (°)

β : Angle of the reinforcement from the horizontal direction (usually equal to 0°)

However, R_{WX} shall be the value that is obtained by multiplying a friction coefficient $\tan\delta_W$ by the vertical component of R_W.

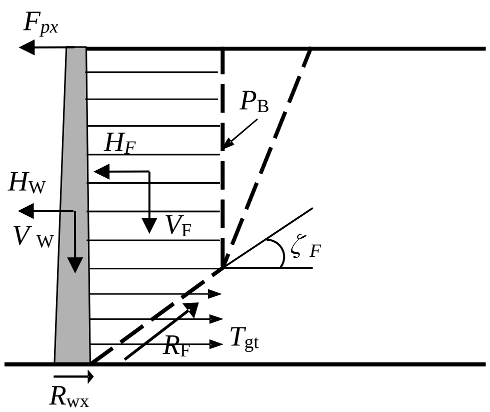


Fig.2.6.3-3 Forces for stability against sliding

ii. Calculation of yield seismic intensity in the overturning mode:

The yield seismic intensity shall be calculated from an equilibrium of overturning moment about the toe of the facing taken as the center of rotation.

$$y_i \cdot \frac{M_{Rd}}{M_{Ld}} \leqq 1.0 \qquad \text{(Equation 2.6.3-4)}$$

where y_i : Structure coefficient (1.0, in general)

M_{Rd} : Design overturning moment (kN·m/m)

M_{Ld} : Design overturning resistance moment (kN·m/m)

$$M_{Rd} = H_W \cdot (y_W - y_c) + H_F \cdot (y_F - y_c) + P_B \cdot \cos(\delta_B - \alpha) \cdot (y_P - y_c) + R_F \cdot \cos(\Phi - \zeta_F) \cdot (x_{RF} - x_c) + F_{px} \cdot (y_{pole} - y_c) + M_{pole}$$

$$M_{Ld} = V_W \cdot (x_W - x_c) + V_F \cdot (x_F - x_c) + P_B \cdot \sin(\delta_B - \alpha) \cdot (x_P - x_c) + R_F \cdot \cos(\Phi - \zeta_F) \cdot (x_{RF} - x_c) + \Sigma T_{gt} \cdot (cos\beta \cdot (y_{gt} - y_c) + \sin\beta \cdot (x_{gt} - x_c))$$

where V_W, H_W : Self weight and horizontal seismic inertia force of the facing (kN/m)

x_W, y_W : The gravity center of the facing

V_F, H_F : Self weight and horizontal inertia force of Block Ⓕ (kN/m)

x_F, y_F : The gravity center of Block Ⓕ

P_B : Total resultant earth pressure acting on the back of Block Ⓕ (kN/m)

δ_B : Angle of P_B relative to the horizontal direction

x_P, y_P : The point of action of P_B

t_{gt} : Resistance force of the reinforcement (kN/m)

β : Angle of the reinforcement relative to the horizontal direction

x_{gt}, y_{gt} : The point of action of the force of the reinforcement

R_F : Reaction force acting on the base of Block Ⓕ

Φ : Internal angle of friction (peak friction angle) of the backfill

x_{RF}, y_{RF} : The point of reaction R_F

α : Angle of the back face of the facing relative to the vertical direction

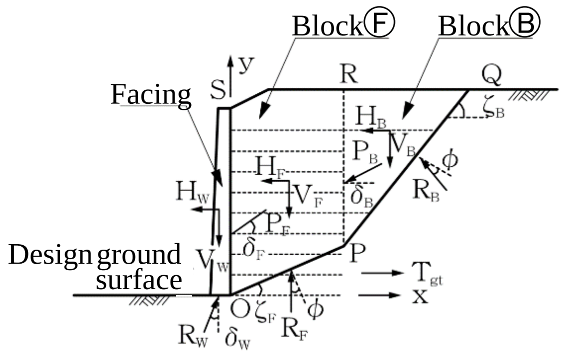
x_c, y_c : Rotation center of the facing

F_{px} : Horizontal load acting on the facing

F_{py} : Vertical load acting on the facing

M_{pole} : Moment acting on the electric pole

x_{pole}, y_{pole} : Coordinates of the point of action



<Schematicview for calculation>

3) Residual displacement is determined by the Newman method (Annexed Document 13 to the Design Standard for Earth Retaining Structures):
The residual displacement of reinforced soil shall be calculated by the Newmark method similarly as in the case of earth pressure-resisting retaining wall. In the analysis by the Newmark method, the residual displacement shall be calculated on the assumption that the displacement of GRS RW will accumulate due to the seismic inertia force that will exceed the yield seismic intensity in each displacement/deformation mode as calculated in 1) above.
Fig. 2.6.3-4 shows a schematic diagram of displacement calculations. After the start of yielding, ϕ_{res} shall be used for the internal friction angle of the retained backfill, and displacement calculation shall be made for both of the plus and negative sides of waveform.

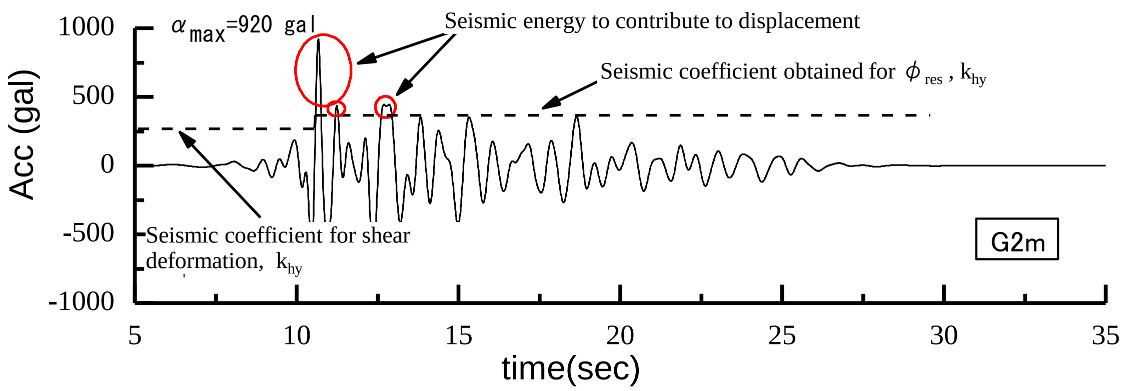


Fig. 2.6.3-4 Schematic figure illustrating the method of displacement calculation by the Newmark method

4) Calculation of residual displacement/deformation by (Annexed Document 13 to the Design Standard for Earth Retaining Structures):
The calculation of displacement/deformation due to Level 2 design seismic load shall be made by the Newmark method. Here, the residual displacement/deformation shall be calculated by the Newmark method from the equation of motion for the sliding mode or

overturning mode of the GRS RW. The residual for the motion equation for sliding and overturning and shear deformation are shown below.

i. Equation of motion for the sliding of the reinforced soil:

$$M\ddot{\delta} = H_{Rd} - H_{Ld}$$

where δ : Displacement

M : Inertia mass of the facing and Block Ⓕ

H_{Rd} : Design sliding force

H_{Ld} : Design sliding resistance force

ii. Equation of motion for the overturning of the reinforced soil:

$$J\ddot{\theta} = M_{Rd} - M_{Ld}$$

where Θ : Rotational angle

J : Inertia moment of the facing and Block Ⓕ

M_{Rd} : Design overturning moment

M_{Ld} : Design overturning resistance moment

iii. Equation for calculating the residual horizontal displacement at the top of the facing due to the residual shear deformation of the reinforced zone:

From the result of shaking table model tests on GRS RW having FHR facing, it has been observed that the facing tilts forward with the result that the reinforced zone back of the facing showed essentially uniform shear deformation (Refer to Fig. 2.6.3-5). This deformation shall be regarded as simple shear deformation, and the shear deformation shall be calculated by an equation for estimating residual displacement from the law of constant energy shown below.

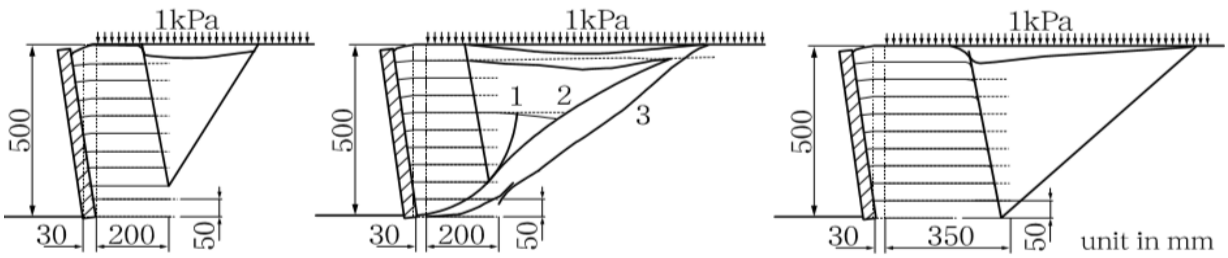


Fig. 2.6.3-5 Shear deformation by shaking in the shaking table model tests of "GRS RWs"

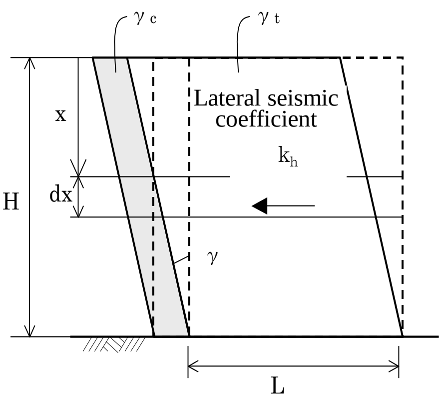


Fig. 2.6.3-6 Shear deformation mode

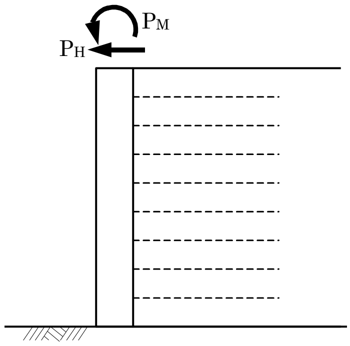


Fig. 2.6.3-7 Loads acting on the crest of the facing

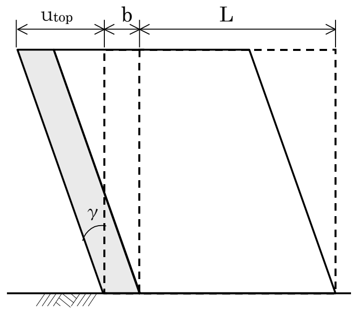


Fig. 2.6.3-8 Shear deformation mode

$$U_{top} = \frac{(k_h - k_y)}{G_P} \gamma_t \lambda H^2$$

$$\lambda = \frac{1}{2}\left\{\left(1 + \omega + \frac{2p}{y_t H}\right) + \beta\left(\frac{H}{3L} + \frac{p}{y_t L}\right)\right\} + \frac{1}{y_t L H^2}\left(P'_H H + P'_M\right)$$

$$k_y = \frac{\bar{L}}{2H}$$

$$\omega = \frac{y_c b}{y_t L}$$

where u_{top} : Residual horizontal displacement at the crest of the facing

ω : Inertia effect of the facing

k_h : Lateral seismic coefficient (Acceleration/Gravitational acceleration)

p : Surcharge loads

k_y : Yield seismic coefficient for shear deformation

β : Coefficient of dynamic earth pressure (= 0.75)

G_P : Shear modulus of rigidity for the plastic deformation of the reinforced backfill

y_c : Unit weight of the facing

y_t : Unit weight of the backfill material

b : Width of the facing

H : Height of the facing

L : Width of reinforced region

P'_H, P'_M : Horizontal force and moment per unit seismic coefficient

Further, the calculation of the shear modulus for the plastic deformation of reinforced backfill is obtained as follows.

$$G_P = 0.2 \cdot G_o$$

G_o : Initial shear modulus for elastic deformation of the backfill soil (kN/m^2)

In this calculation of the shear modulus for the plastic deformation of the reinforced backfill, both of an increase with an increase in the confining effect caused by the laying of the reinforcement in the backfill and a decrease with an increase in the shear deformation of the reinforced backfill are taken into consideration. From the back analysis of the results from the shaking table model tests, it was confirmed that the shear modulus for plastic deformation, G_p, becomes approximately 0.2 times the initial shear modulus, G_o, of the retained backfill material. Also, the initial shear modulus, G_o, shall be calculated from the value set forth in Annexed Document 12-1 to the Aseismic Design Standards, with taking into consideration the type of the backfill material and the confining pressure at the middle height of the reinforced zone.

(2) Calculation of settlement of the backfill:
The area created by horizontal displacement in the modes of sliding, overturning and shearing is calculated as:

$$A_h = (\delta_{hSL} \times H + \delta_{hOT} \times H/2 + \delta_{hSH} \times H/2)$$

Where A_h : Horizontal displacement area
H : Height of the facing
δ_{hSL} : Horizontal displacement by sliding
δ_{hOT} : Horizontal displacement by overturing
δ_{hSH} : Horizontal displacement by shearing

The area created by settlement in the backfill in the modes of sliding, overturning and shearing is calculated as:

$$A_v = (\delta_{vSL} + \delta_{vOT} + \delta_{vSH}) \times (B)$$

Where A_v : Vertical displacement area
δ_{hSL} : Vertical displacement (settlement) by sliding
δ_{hOT} : Vertical displacement (settlement) by overturning
δ_{hSH} : Vertical displacement (settlement) by shearing
B : Width of the region inside the range where the failure plane develops by the seismic coefficient inducing the yielding of shear deformation, where the settlement takes place in the backfill.

From $A_h = A_v$, the settlement at the crest of backfill is obtained from the horizontal displacements caused by sliding, overturning and shearing of the backfill is obtained as:

$$\Sigma\delta_v = (\delta_{vSL} + \delta_{vOT} + \delta_{vSH}) = (\delta_{hSL} \times H + \delta_{hOT} \times H/2 + \delta_{hSH} \times H/2) / (B)$$

In this calculation, it is assumed that the area created by horizontal displacements due to sliding and overturning displacements and shear deformation, A_h, is the same as the area created by the settlement taking place within a range inside the failure plane that develops when shear yielding takes place (Fig. 2.6.3-9).

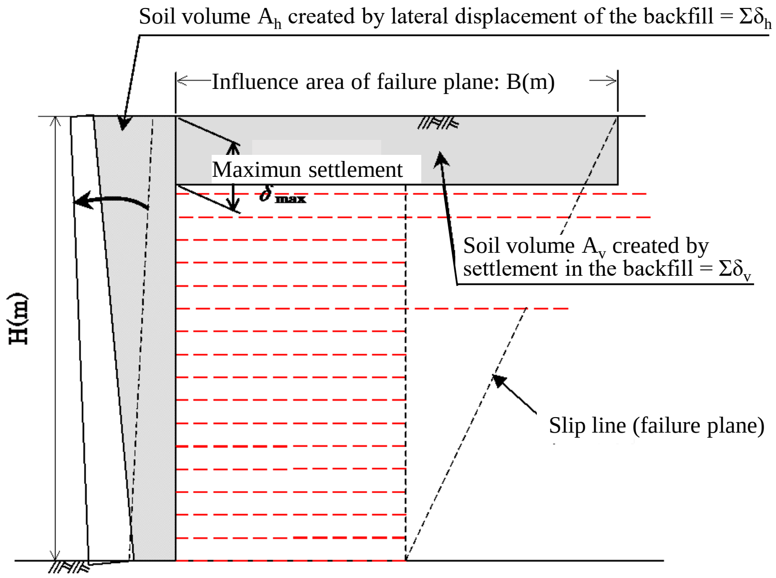


Fig. 2.6.3-9 Schematic diagram illustrating method of settlement in the retained backfill

2.6.4 Verification of Satisfactory Performance of the RC Facing and the Reinforcement

A detailed examination of the rupture of the reinforced-concrete RC facing and the geotextile reinforcement of the GRS RW shall be made by using the design response values of earth pressure acting on the back face of the facing calculated by modeling the RC facing as a continuous beam of the elastic body and the geotextile reinforcement and the retained backfill as a series of spring support.

[Commentary]

(1) Calculation of design response values:

A detailed examination of the rupture of the RC facing and the geotextile reinforcement of the GRS RW shall be made by using the design response values of earth pressure acting on the back face of the facing as calculated by modeling the RC facing as continuous beam of the elastic body and the geotextile reinforcement and the retained backfill as a series of spring support, as shown in Fig. 2.6.4-1.

In this analysis, the RC facing above the embedded depth at the bottom face of the facing foundation shall be modelled. The applied external forces shall be the earth pressure acting on the back face of the RC facing, the dead weight of the RC facing, the inertia force of the RC facing by an earthquake, and the component in the direction normal to the facing of the external force acting on the top of the RC facing. On the other hand, the earth pressure acting on the RC facing is considered to be in between the active earth pressure as determined by the two wedge method and the earth pressure at rest, depending on the degree of the restriction of the deformation of the backfill by geotextile-reinforcing. Here, the earth pressure at rest shall be used on the safe side.

The coefficient of earth pressure at rest, K_o, shall be determined by Jaky's formula ($K_o = 1 - \sin\varphi$). Further, the coefficient at the time of an earthquake shall be equal to $K_o (1 + k_h)$. The details shall be in accordance with 8.3.4 of the Design Standard for Earth Retaining Structures.

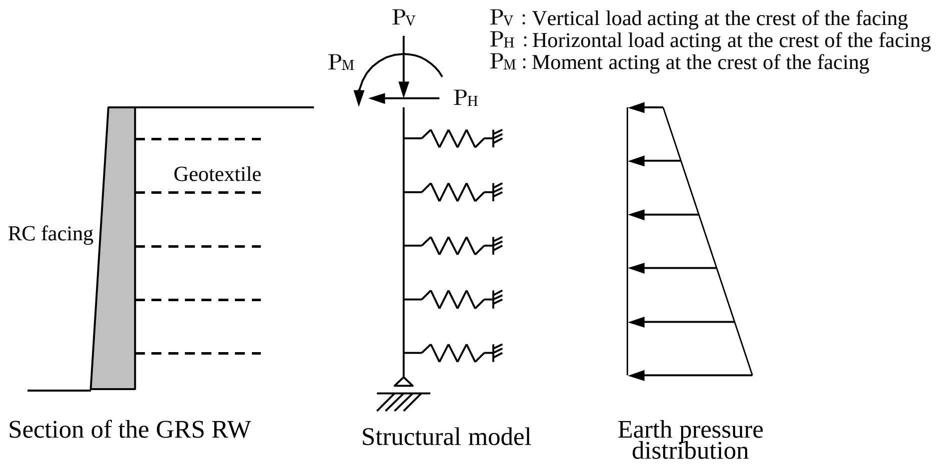


Fig. 2.6.4-1 Structural model of RC facing of GRS RW

(2) Detailed examination of the rupture of the geotextile reinforcement:

The purpose of the detailed examination of the rupture of the geotextile reinforcement shall be to confirm that the limit value of the tensile strength of the reinforcement as determined as described in (1) above is met.

(3) Detailed examination of the stress of the RC facing:

The detailed examination of the stress of the RC facing shall be carried out by conducting detailed examination of the safety and usability/restorability of the reinforced-concrete component acting in each cross-sectional section in accordance with the Design Standard for Concrete Structures to be applied mutatis mutandis. In this case, the minimum steel reinforcement content which is the premise for the detailed examination described above, and examination of the structural details shall be in accordance with the Design Standard for Concrete Structures.

Chapter 3 Construction

3.1 Construction Plan

3.1.1 Construction Plan - General

In formulating a construction plan, the features of the RRR-B Construction Method shall be fully recognized, while bringing the plan in alignment with the landform, geological features, etc. of the site so that the construction will meet the dimensions and quality that are shown in the design documents.

[Commentary]

It is necessary that the contents of the construction plan be such that it will be in alignment with actual works, and works will be carried out smoothly, safely and economically according to the plan.

Hence, in making a construction plan, it is necessary to predict and study various conditions and problems that are characteristic to the site, such as effects of the construction works on transportation in service during the construction period, while taking account of the design conditions, purpose of the structure and the features of the RRR-B Construction Method at the same time.

Main investigation and study items involved in the formulation of the construction plan are as follows:

i. Landform, geographical features and meteorological conditions
ii. A materials plan and a temporary structure plan
iii. Construction method and a plan for construction machinery
iv. Construction management plan
v. Schedule and a manpower plan
vi. Safety and sanitation management plan
vii. Other

Other items include a test embankment and measurement management plan. They shall be studied, depending on the construction period and the conditions of the site.

3.1.2 Construction Procedure

The construction procedure shall be carried out after making a careful study of the contents of the works and the works conditions at each site so that the construction under the RRR-B Construction Method will be carried out smoothly and securely.

[Commentary]

Fig. 3.1.2-1 shows a rough flow of the construction under the RRR-B Construction Method. An outline of the construction procedure is as follows:

i. In preparation for the construction work, an investigation/confirmation of the existing underground facilities, preparatory surveying and clearing/grubbing shall be done.
ii. The excavation and site preparation of the surface of the ground supporting the embankment shall be carried out.
iii. After excavation has been completed up to the specified embankment ground surface, the excavation of the foundation portion shall be carried out, and the construction work for the foundation material and the placing of levelling concrete shall be carried out.
iv. The assembly of the reinforcing steel rods for the RC facing, assembly of the forms and the casting of concrete for the embedded section of the facing shall be carried out.
v. The bench-cutting of the slope shall be done at each specified height.
vi. The geotextile reinforcement layers shall be arranged.
vii. The wall face shall be temporarily supported by the use of gravel bags, etc. and they shall be wrapped around with the geotextile layer.
viii. The backfill material shall be placed, leveled and rolled.
ix. The assembly of the scaffolding, assembly of facing reinforcing steel rods, assembly of forms and casting of concrete shall be done.
x. The installation of a drainage ditch in front of the facing and cleaning-up shall be done.

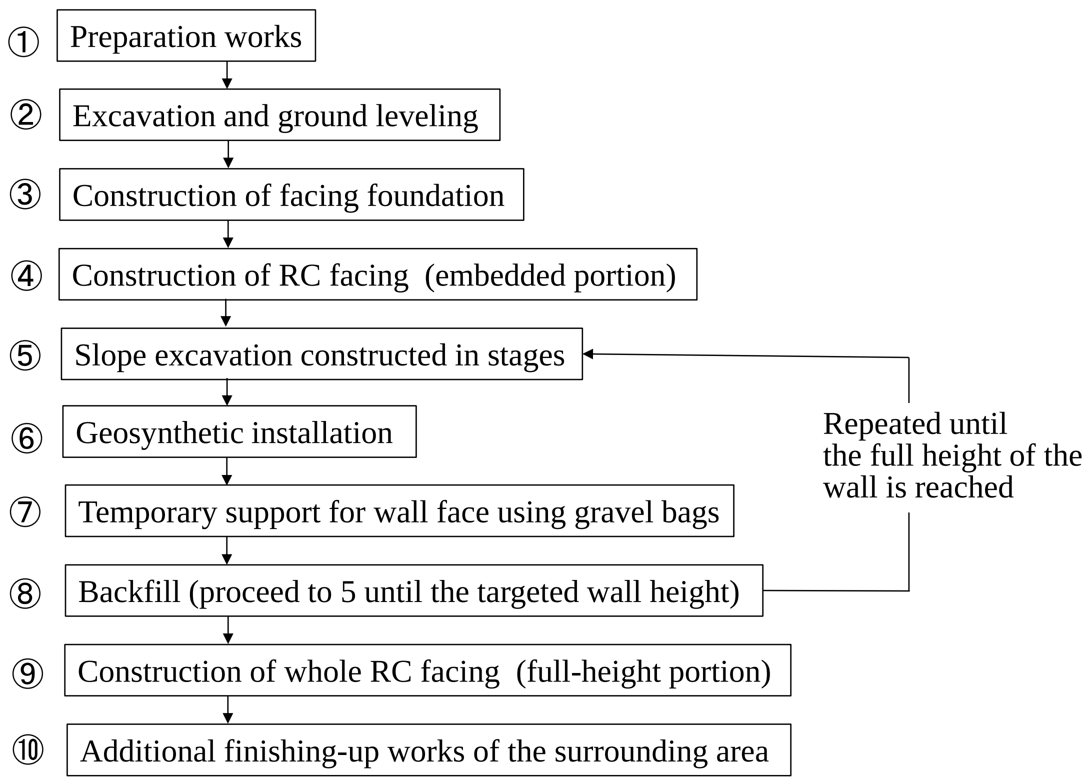


Figure 3.1.2-1 Construction flow of RRR-B method

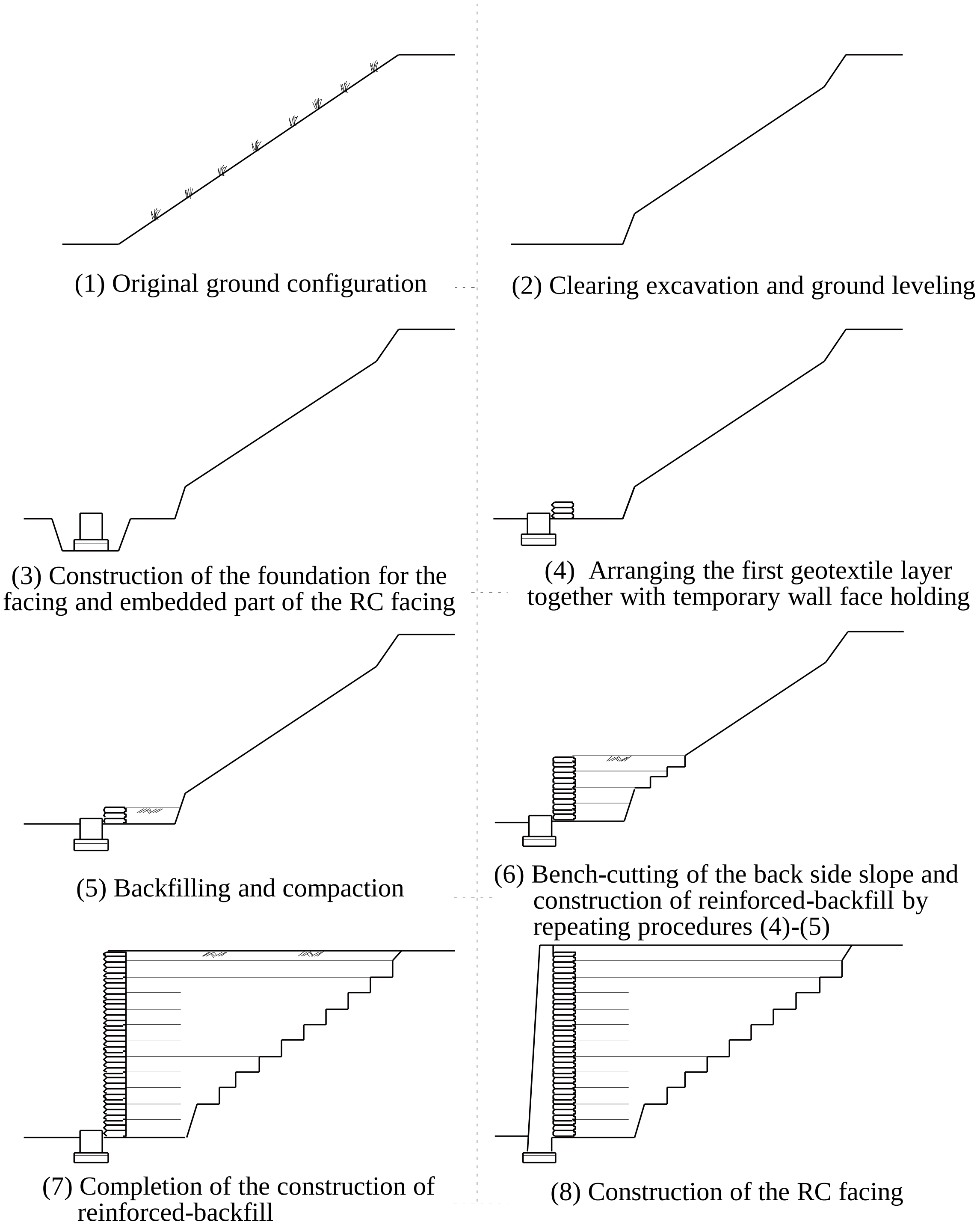


Fig. 3.1.2-2 Construction work procedures of RRR-B method
(Case of widening of an existing embankment)

3.1.3 Materials Plan

With respect to the materials necessary for the construction, the delivery time, delivery method and delivery date for them shall be determined on the basis of the specifications, shape, dimensions, quantities, etc. as captured on the basis of the design documents.

(1) Backfill material: The backfill material for the construction shall be used after it is confirmed that the material is the one specified in 2.4, Materials and Ground.

(2) Concrete, steel materials, etc.: The use of the concrete, steel materials, etc. for the RC facing with regard to (6) above shall be planned on the basis of the specifications, shape, dimensions, quantities, etc. to meet the conditions at the site according to the construction schedule.

(3) Geotextile: The delivery time, method and place of the geotextile for use under the RRR-B Construction Method shall be determined on the basis of the specifications, shape, dimensions, quantities, etc. as captured on the basis of the design documents.

[Commentary]

With regard to (1) above:

It is necessary that the backfill materials for use under the RRR-B Construction Method conform to the design documents and be compacted properly (satisfying the requirements for the design soil values, γ, c and φ). Since the geotextile is laid at the boundary between the vertically adjacent rolling compaction layers, care should be taken to remove any backfill material having an extremely large diameter because it will damage the geotextile or inhibit the engagement of the geotextile and soil.

With regard to (3) above:

The geotextile registered in the Materials Manual shall be used under the RRR-B Construction Method. Be sure to capture the specifications, shape and dimensions, quantities, etc. of the materials having a level of strength higher than the design rupture strength (normally; $T_{aj}=T_a \times \alpha_j$; temporary: $T_{ai}=T_a \times \alpha_i$; at the time of earthquake: $T_{ae} = T_a \times \alpha_e$; for details, refer to the Materials Manual) and additionally study the following items:

i. Determination of delivery time
ii. Handling method at the working site
iii. Availability of storage space and storage method
iv. Safety measures

Since the geotextile deteriorates due to ultraviolet rays, it shall be stored in such way that it will not be exposed to the sun light for a long time. Also, any geotextiles having water holding properties, such as nonwoven fabric, shall be stored in such way that they will not be exposed to the rain.

3.1.4 Work Plan

The work plan shall be a proper one for the work to be carried out securely and efficiently in accordance with the construction procedure.

[Commentary]

1) In formulating the work plan, the following items shall be studied so that they will be appropriate ones:
   i. Work scale and environment
   ii. Type of the backfill material
   iii. Combination of construction machinery
   iv. Construction period and time of construction
   v. Construction environment (noise, vibration, underground facilities, overhead wire, etc.)
   vi. Construction road and small-scale transport

2) One of the characteristic features of the RRR-B Construction Method is that it can be carried out in a narrow place. It goes without saying that, in such work environment, measures and efforts shall be taken to carry out the construction efficiently. In addition, a study shall also be made with regard to safety in the construction and environmental preservation. As for the underground facilities and overhead wire, among other things, adequate discussion shall be held with the organizations concerned prior to the execution of the work to formulate a work plan.

3) Under the RRR-B Construction Method, if compaction is insufficient or any equipment unsuitable for soil compaction is used, not only will a desired level of strength of the backfill not be achieved, but also there will be voids and loose zones left in the backfill, and as a consequence, settlement will occur in the backfill. Therefore, an adequate study shall be made of the construction method including the selection and combination of machinery suitable for the backfill material, and the spreading method, and the compaction method including the capacity, the number of pass and the speed of compaction machine.

4) Under the RRR-B Construction Method, to keep the vertical or near vertical wall face stable during the period up to the construction of the RC full-height rigid facing, a temporary holding material using gravel-filled bags or welded wire mesh boxes filled with gravel will be required to be properly arranged at the temporary wall face. Besides, large-scale construction machinery cannot be used for the spreading, leveling and compaction of the backfill material, but small-scale machinery will be used for such work. For this reason, it is necessary to make a work plan to match the work scale and the work environment.

5) With regard to the machinery and materials for use in the construction work and the road for use for the transportation of the backfill material, do not fail to take account of noises, vibrations, pollution, etc. for households in the neighborhood that will be emitted at the time of the passage of transportation vehicles in addition to traffic restrictions including road width and restrictions for vehicle passage.

6) In the case where gravel bags are used for the temporary wall face holding and the fabrication and small-scale transport of gravel bags are carried out by human labor, the burden on the workers will be great. Depending on the scale of the construction, it is necessary to consider proper arrangements necessary for gravel bags fabrication equipment, a yard for the fabrication of gravel bags, a method for transporting gravel bags to a stacking place and a method for small-scale transport.

3.1.5 Safety Plan

The safety plan shall be a proper one for the work to be carried out securely and efficiently in accordance with the construction procedure.

[Commentary]

1) If it rains during the construction period, the surface of the unfinished surface of the slope that is under the process of cutting shall be properly treated by covering it with sheets (in the case of the construction of GRS RW on the slope of existing embankment).

2) In the event that any changes occur in the vicinity of the slope top area, including cracks or changes in the side ditch, such occurrences shall be reported to the supervisors, the work shall be promptly suspended, and the workers shall follow the instructions of the supervisors.

3) Proper measures shall be taken to ensure that there will be no fall of personnel or equipment from the top of the embankment.

4) When carrying out the construction in the vicinity of a line open to traffic, a train sentinel (a qualified person) shall be assigned to the site, and the train sentinel’s signals shall be followed strictly.

3.1.6 Construction Schedule Plan

The construction schedule plan shall be so formulated that the work will be carried out securely and efficiently in accordance with the construction method and procedure.

[Commentary]

The amount of construction is expressed by the following equation:

(Amount of construction) = (Number of workable days) x (Standard daily work)

The number of workable days is the number of days obtained by subtracting the number of holidays, days on which work cannot be done due to natural conditions, days of preparations, etc. from the number of calendar days. The amount of the standard daily work refers to the amount of standard work per one day of use of equipment.

The number of workable days and the amount of the standard daily work are greatly variable depending on the natural conditions, social conditions, construction environment, etc. In particular, the work by the RRR-B Construction Method consists primarily of civil engineering works and accordingly is highly affected by the natural conditions. For this reason, the construction schedule plan shall adequately reflect the information obtained from an investigation into meteorological conditions, etc.

In Japan, since the amount of rainfall is large, care should be taken in making a construction schedule plan if the construction period falls in the rainy season or the construction is carried out in a region where there is much snow or rain.

3.2 Construction Method

3.2.1 Preparatory Works

Preparatory works are those works which are carried out to prepare the basis for the execution of the construction. Specifically, preparatory works include the following:

(1) A site survey

(2) Confirmation of underground facilities and existing structures

(3) Clearing, grubbing and surface soil removing

These are done to enable subsequent construction works to be carried out smoothly.

[Commentary]

Under the RRR-B Construction Method, preparatory works shall be done to gain an accurate understanding of the conditions of the site and to eliminate anything that will become an obstacle to the stability and construction of a GRS structure. Such preparatory works will have a significant effect on the subsequent construction method, construction speed, outcome, etc. Therefore, an adequate investigation and study shall be made so that the method most suitable for the contents of the works will be adopted.

With regard to (1) above:

If the conditions at the site differ greatly from the design, the conditions at the site shall be promptly confirmed by conducting a site survey, etc. because it may become necessary to review the construction method and the design.

Furthermore, in construction in the vicinity of the site boundary, it is necessary to confirm the site at the boundary. In construction in such case, the construction method and the survey method have to be studied so that the structure will not infringe on the boundary through the deformation or movement of the form or timbering that may occur during the construction of the structure under the RRR-B Construction Method. Furthermore, prior consultation shall be held with the parties concerned about the identification of the boundary and the construction method.

With regard to (2) above:

There is a high possibility that the presence of an obstacle will have a serious effect on the stability of the reinforced embankment in such case where there is a buried object in the location of the laying of the geotextile that makes it difficult to carry out the construction as designed. Accordingly, it is necessary to confirm the presence and location of a buried object or an existing structure and to study its removal or relocation as possible. Furthermore, if any existing structure is close to the excavated slope (bench-cut surface), it may have an effect on the stability of the existing structure itself, and consequently, it is necessary to fully understand the extent of such effect.

With regard to (3) above:

Any trees and plants on the foundation ground of a reinforced embankment or the existing slope of an expanded embankment or the surface of the soil-gathering place shall be removed prior to the construction. This clearing and grubbing are important for preventing any future effects, such as the deformation of the embankment and the occurrence of slide due to the occurrence of humus. After clearing and grubbing, the surface soil shall be removed by approximately 300 mm, and the formation level shall be prepared.

3.2.2 Excavation Work and Preparation of the Formation Level

Prior to the laying of the geotextile on the first soil layer, the following work shall be carried out:

(1) Excavation of the bottom step of an existing slope

(2) Preparation of the formation level

Moreover, the following work shall be done as required:

(3) Drainage works on the foundation ground

[Commentary]

With regard to (1) above:

In the construction of reinforced embankment that is added to an existing slope, it often happens that the length of the geotextile that can be laid at the bottom step is insufficient. The bottom step of the existing slope has to be bench-cut (Fig. 3.2.2-1). 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 shown in the design document.

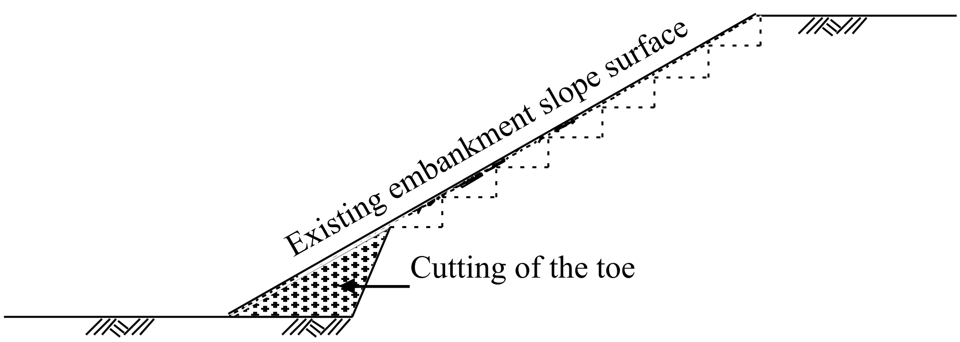


Figure 3.2.2-1 Cutting at the toe of existing embankment

With regard to (2) above:

Prior to the construction of a reinforced embankment, the unevenness of the installation base surface shall be eliminated so that the laying of the geotextile on the flat base surface and the drainage on the base surface will be carried out smoothly, and the base surface shall in principle

be prepared horizontal and flat. Care should be taken that such work will not interfere the foundation ground or the existing embankment unintentionally.
In the case where the embankment foundation ground is soft soil, such as humus soil, having low strength and high compressibility, there is a possibility that a harmful settlement will take place. For this reason, the ground needs to be improved by such measures as replacing the backfill material with a high-quality material to a necessary depth.
If the foundation ground is a rock bed or has many gravel fractions showing many irregularities, a high-quality backfill material shall be placed and leveled, and the ground shall be prepared so that there will be no harmful unevenness. A great extent of unevenness may cause damage to the geotextile and have an adverse effect, such as a decline in the friction effects in geotextile-reinforcement.

<u>With regard to (3) above:</u>
The RRR-B Construction Method basically maintains stability by means of the friction force at the interface between the geotextile and the backfill material. Therefore, a rise in the pore water pressure in the embankment will cause a big problem for the stability of the embankment. Consequently, if there is spring water in the embankment ground, it becomes necessary to carry out foundation drain works, including underdrains (Fig. 3.2.2-2).
Furthermore, it is preferable that a drain layer (for example, a nonwoven geotextile layer) be installed on the foundation surface to prevent a rise in the groundwater level, by the drain of permeated water, etc.

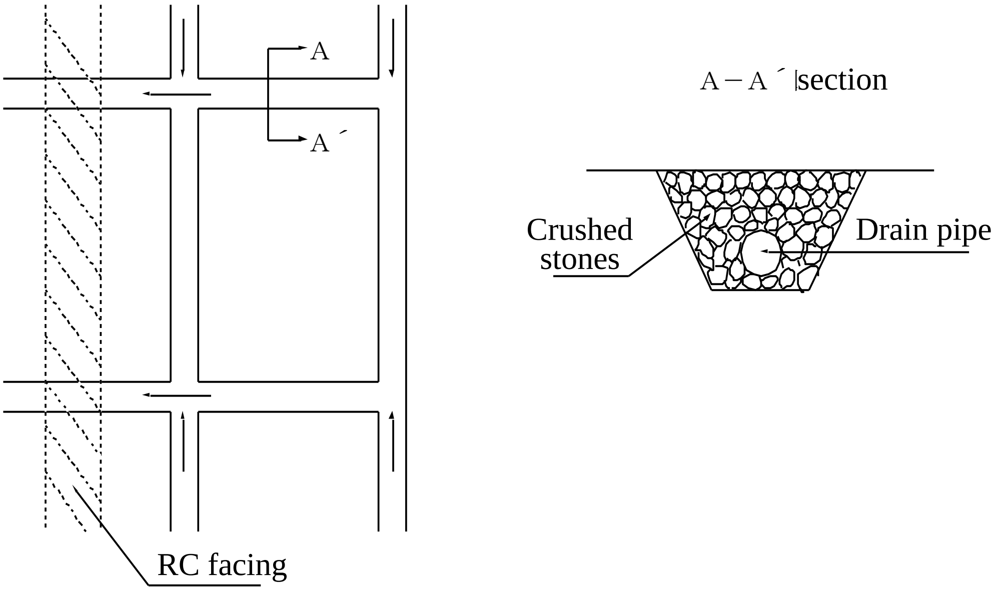


Figure 3.2.2-2 Underdrain at the foundation ground

Photo 3.2.2-1 Installation of drain blanket on the base ground

3.2.3 Foundation Works

The foundation works may be such that it is capable of retaining the dead weight of the RC facing section and the vertical component of the earth pressure that acts on the back of the RC facing. The foundation works shall be carried out to meet the conditions at the construction site.

[Commentary]

Generally, the foundation of the RC facing section constructed by the RRR-B Construction Method may be such a simple one as illustrated in the details of the structure. 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. However, the underground section (i.e., the embedded section of the facing) of the facing shall be constructed prior to the construction work of the embankment (Fig. 3.2.3-1).

In carrying out the construction of the foundation for the RC facing, the foundation material, such as high-quality backfill material shall be placed on the finished ground surface and finished to the specified height, while taking care that the ground surface will not be disturbed. The foundation material shall be adequately rolled and leveled to finish it to the specified level, and then concrete shall be cast.

In the case where the foundation is constructed on a rock bed, adjusting and levelling concrete shall be placed to eliminate unevenness.

In the case where there is a longitudinal slope at the site, a stair-type foundation is constructed, but the ground at the upper step of the foundation is often disturbed when the ground is excavated to steps. Since this may lead to a differential settlement of the RC facing, any disturbed zones shall be adequately prepared and compacted by the use of a good-quality backfill material (Fig. 3.2.3-2).

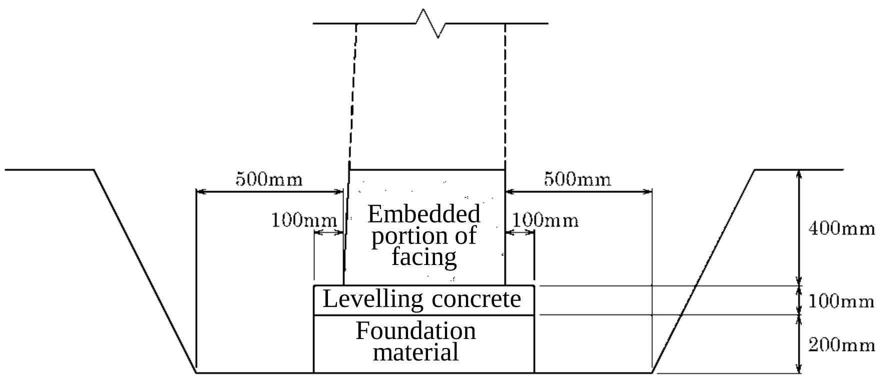


Figure 3.2.3-1　Foundation of the RC facing　（example）

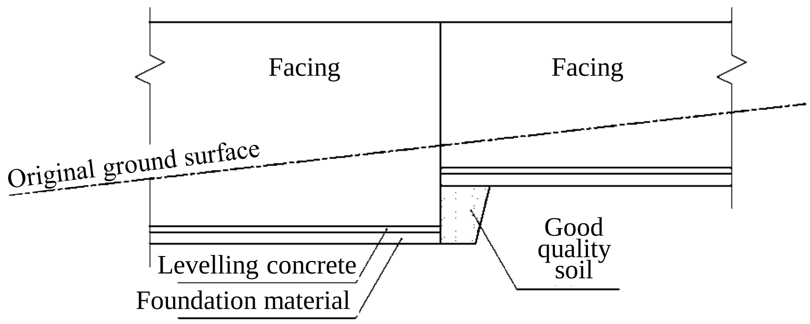


Figure 3.2.3-2　Foundation works conducted in stages　（example）

3.2.4　Bench Cutting

In the case where an embankment is constructed by the RRR-B Construction Method by being added to an existing slope, the slope shall be bench-cut, and it shall be ensured that the reinforced embankment and the existing slope will be integrated so that the stability of the embankment will be secured.

[Commentary]

In the case where an embankment is constructed by the RRR-B Construction Method by being added to an existing slope, there is a possibility that a failure plane will be formed at the boundary with the existing slope, causing a sliding failure. To prevent this, the existing slope shall be bench-cut, and the added embankment shall be constructed to be integrated to the existing natural ground or embankment.

The bench-cutting of the existing slope shall be carried out according to the inclination of the slope of the existing natural ground or embankment.

It is preferable that the height of a step of the bench-cutting of the existing slope be approximately 2 times (approximately 600 mm) the thickness of one finished soil layer of backfill.

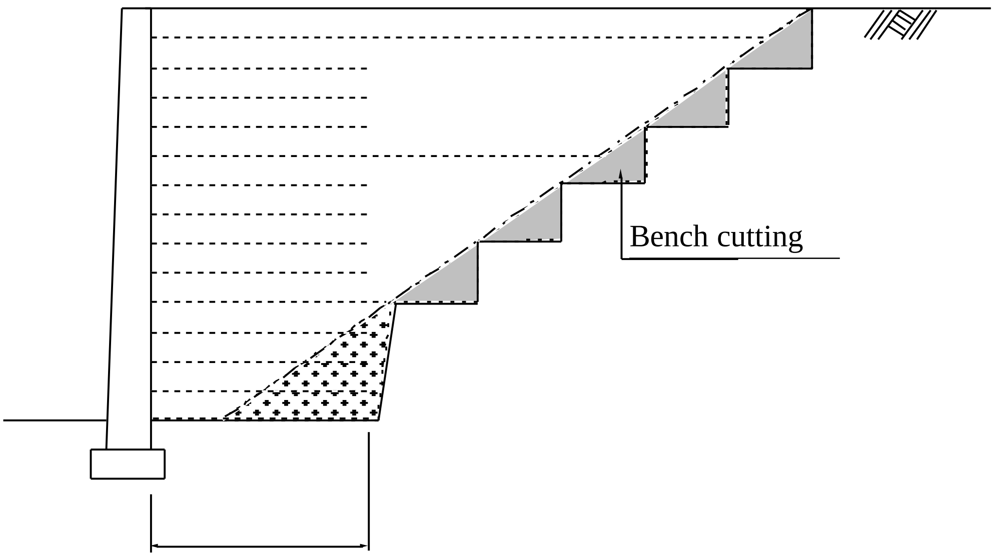


Figure 3.2.4-1 Bench-cutting of existing embankment slope surface

3.2.5 Laying of the Geotextile

In laying the geotextile, the following items shall be taken into consideration:

(1) A geotextile of the specified properties, form and length shown in the design documents shall be laid in the specified location.

(2) The geotextile shall be laid horizontal and in such manner that there will be no extreme unevenness or gap.

(3) The geotextile shall be laid at right angles to the RC wall facing.

(4) Seams of the geotextile shall not in principle be provided in the direction perpendicular to the facing.

[Commentary]

<u>With regard to (1) above:</u>

In carrying out the laying of the geotextile, care shall be taken to ensure that a geotextile that meets the specifications for the form and level of strength above the product guaranteed strength (T_{aj}, T_{ai}, T_{ac}) that are shown in the design documents will be laid in the specified areas at the site. Furthermore, the physical properties, shape, length, etc. of the geotextile for use are key matters for the construction under the RRR-B Construction Method and shall in principle be specified in the design documents (design drawings and design calculations).

<u>With regard to (2) above:</u>

Since the geotextile is subject to the tensile forces basically acting in the horizontal direction, if there is any extreme unevenness or gap with the geotextile laid, it is possible that the deformation that will occur until the geotextile begins to work effectively, and problems such

as the occurrence of large deformation in the embankment will arise. For this reason, the geotextile has to be laid horizontal and in such way that there will be no occurrence of extreme unevenness or gap. Therefore, if there is any unevenness on the finished surface of the backfill, the geotextile shall be laid after such unevenness is corrected. Furthermore, if there are any rock fragments, etc., they may damage the geotextile, and they shall be removed.
It is preferable that the geotextile be temporarily supported here and there during the period from the time of the laying of the geotextile to the spreading of the backfill material so that a gap will not occur due to strong wind, etc.

With regard to (3) above:
The laying of the geotextile shall be carried out by putting the winding-back length to wrap around the temporary wall face holding section having the construction unit height (normally 300 mm or so) outside the wall face while ensuring that its main direction will be perpendicular to the wall face. The wound-back section of geotextile shall be wound back to the main body of embankment at the specified construction stage while wrapping around the temporary holding material system (Figs. 3.2.5-1 and 3.2.5-2). For details on the winding-back of the geotextile in the temporary holding material section, refer to 3.2.6, Temporary holding material.

With regard to (4) above:
It is preferable that the geotextile is a one-piece material having no seams. Depending on the shape and dimensions of the material, however, in some cases, it is unavoidable to have a seam (or seams) in the geotextile. The handling of such seams shall in principle be as described below.
In the reinforced backfill zone, any seams shall not be provided in the main direction of the geotextile, which is perpendicular to the wall face (i.e., the principal direction of geogrid). In the case where it is unavoidable that seams should be provided in a section where geotextile layers are laid extended to the slope at the angle of repose or over the full width of embankment, the laying of the geotextile shall be carried in accordance with 2.5, Structural Details (1) Seams of the Reinforcement.
On the other hand, seams will occur inevitably in the direction in parallel to the wall face (i.e., the transversal direction of geogrid). However, since the transmission of force is not basically expected in this direction, the geotextile shall be laid by overlapping it by 100 mm or so (Fig. 3.2.5-3).
In many cases, the geotextile is cut to the specified dimensions at the site, but it is necessary that proper equipment shall be selected for the cutting.

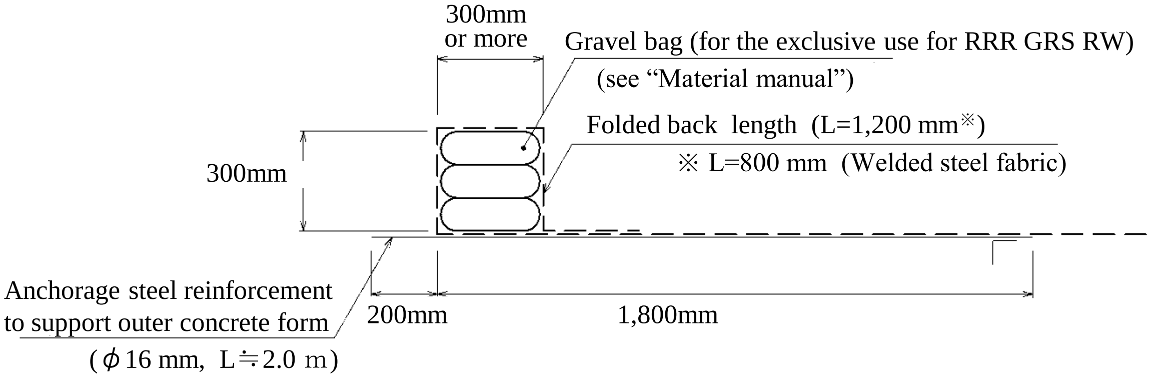


Figure 3.2.5-1 Wrapping geosynthetic layer around gravel bags (gabions)

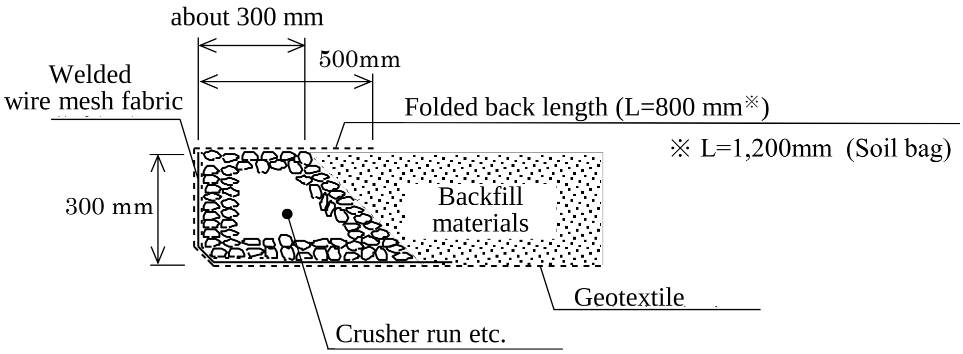


Figure 3.2.5-2 Wrapping geosynthetic layer around welded steel fabric

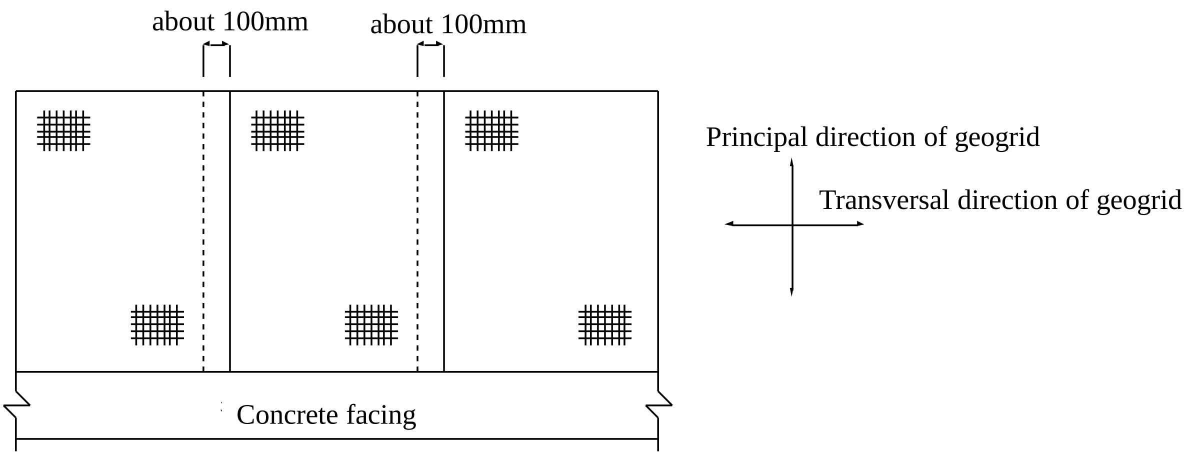


Figure 3.2.5-3 Geosynthetic overlapping

Photo3.2.5-1 Installation of geosynthetic

3.2.6 Temporary holding at the wall face

Under the RRR-B Construction Method, temporary holding shall be provided at the wall face of GRS RW under construction.

[Commentary]

The temporary holding that is used under the RRR-B Construction Method should fulfill the following functions:

- Since the wall face is vertical or near vertical, the temporary holding will ensure the stability of the reinforced backfill during the construction by preventing the backfill material from being pushed out from the wall face.
- After the construction of the GRS RW, the temporary holding will serve as a vertical drain layer.
- The temporary holding will play the role as a buffer material between the RC full-height rigid facing and the geotextile-reinforced backfill having lower rigidity than the RC facing.
- The temporary holding will absorb any differential settlement between the RC facing and the reinforced backfill.

As the temporary holding having the above functions, several materials such as gravel bags, welded steel fabric, expandable metals, etc. have been used on a trial basis. Under the present conditions, gravel bags and welded steel fabric are usually used. As for their structure, refer to the structural details.

(1) Temporary holding using gravel bags:

The characteristic of the use of sandbags for the temporary holding is that the fabrication, small-scale transport, stacking, etc. of the gravel bags are carried primarily by human power, while they are stable when stacked and particularly can flexibly cope with changes in the shape of the wall face, for example.

Generally, the gravel bags used as the temporary holding under the RRR-B Construction Method (refer to the Materials Manual) are filled with a certain amount of a high permeability material such as crushed stone (i.e., crusher run). The filling inlet is sawn by an industrial sewing machine. The finished dimensions shall be approximately 350 mm x 300 mm x 100 mm (Fig. 3.2.6-1).

Not only need gravel bags to be stacked but also the top surfaces of the gravel bags stacked need to be rolled with a tampering machine, etc. so that the voids among the stacked gravel bags will be reduced and get engaged well with each other.

In installing the temporary holding, since the temporary holding will be deformed when compacting the backfill behind. If the deformation is excessive, it may become impossible in the subsequent process to secure the thickness of the RC facing as shown in the design documents for the RC facing in some cases. Accordingly, it is necessary to carry out the construction of the temporary holding gravel bags allowing for its likely deformation.

The fabrication of gravel bags is carried out by use of either human power or equipment with an automatic metering device for making gravel bags. The selection of either of these types shall be made with the construction work scale and the site conditions, among other things.

Further, in the fabrication of gravel bags, the following points shall be taken into consideration:

i. The filling material (crushed stone, crusher run, etc.) shall be filled into gravel bags so that the finished thickness will be approximately 100 mm.

ii. To ensure stability at the time of stacking, the filling inlet shall be closed so that the length will be 300 mm or more.

iii. It is preferable that the filling inlet be sawn with an industrial sewing machine for the purpose of ensuring stability at the time of stacking.

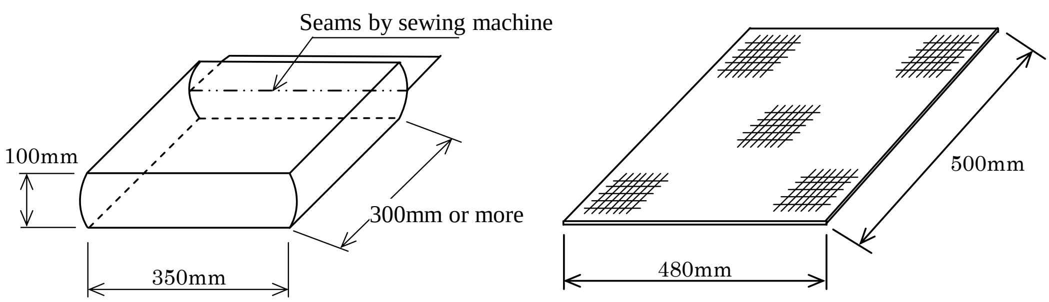
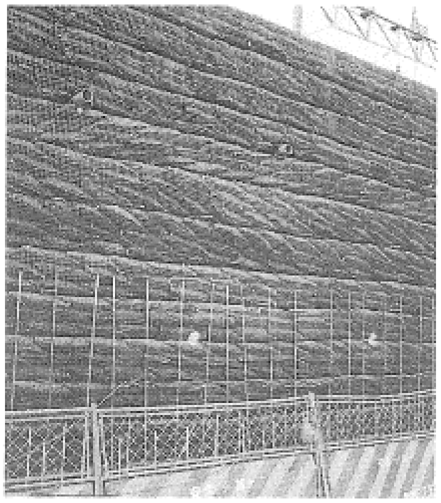
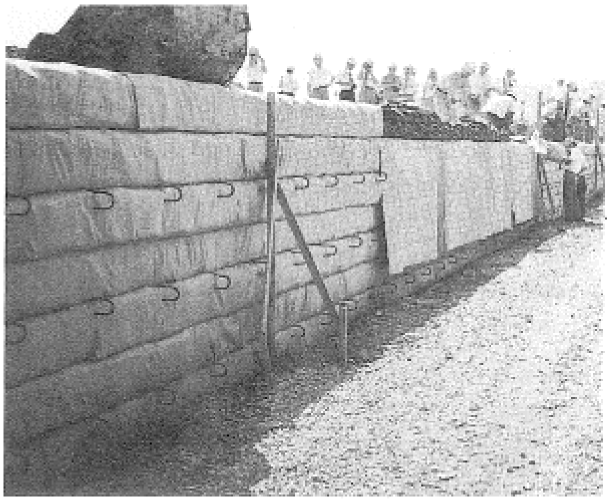


Figure 3.2.6-1 Standard figure of soil bag (gabion)



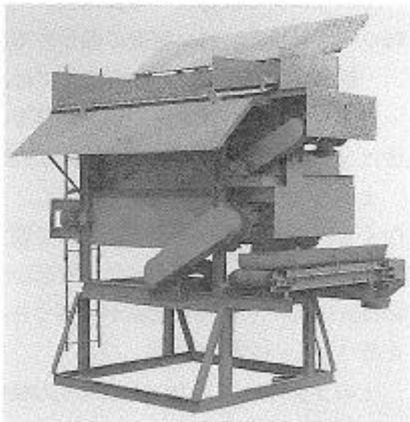
Reinforcement type: geogrid



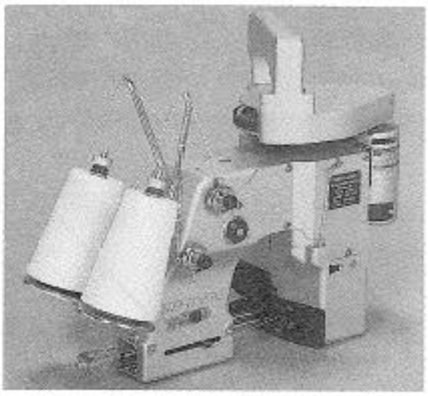
Reinforcement type: nonwoven-woven-nonwoven 3-layer geotextile sheet

Photo 3.2.6-1 Temporary facing support of sandbags

Simplified soil bag production machine



Automatic soil bag production machine



Soil bag sewing machine

Photo 3.2.6-2 Soil bag production machine & sewing machine

(2) Temporary holding using welded steel fabric:

With regard to the types of welded steel fabric to be used, examples of the standard types are given in 2.5, Structural Details, to which reference should be made. The steel rods of this welded steel fabric are bent in advance at the factory, etc. so that the work at the site will be reduced and its installation will be easy. For this reason, it can be expected that its workability at straight wall segments will be high. However, it may be difficult to apply welded steel fabric to any locations in which there are severe undulations in the ground. In that case, combined use of a temporary holding material using gravel bags will become necessary.

In the case where welded steel fabric is used for the temporary holding, welded steel fabric and a geotextile sheet to prevent spilling out of backfill will be installed as illustrated by an example in Fig. 3.2.6-2, and a specified quantity of crusher run will be spread. After that, the backfill material will be spread behind the temporary holding with gravelly soil inside and both will be roller-compacted at the same time. After the completion of compaction, the geotextile that has been placed on the wall face will be turned back to cover the compacted zone.

With the temporary holding using welded steel fabric, it is difficult to carry out an adequate roller-compaction of the temporary holding section alone prior to the spreading of the backfill material behind, due to the lateral displacement of the crusher run section. The basic principle is to roller-compact the temporary holding material section and the backfill section at the same time as described above (Fig. 3.2.6-3).

Further, even in the case where roller-compaction is carried out in two separate layers of 150 mm thick each because it is impossible at a layer thickness of 300 mm to carry out adequate compaction, the temporary holding section and the embankment section shall be eventually roller-compacted at the same time.

With regard to the shape of the wrapped-up portion, it is necessary to ensure that the top width of the gravel bags and the top width of the crusher run should be approximately 300 m, but there is no need to be very particular about dimensional accuracy in other respects.

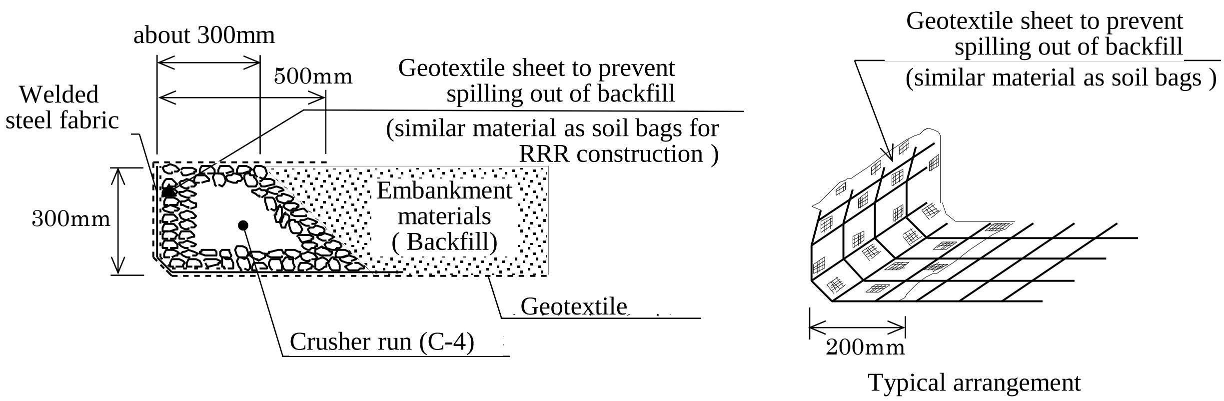


Figure 3.2.6-2 Wrapping geosynthetic layer around welded steel fabric

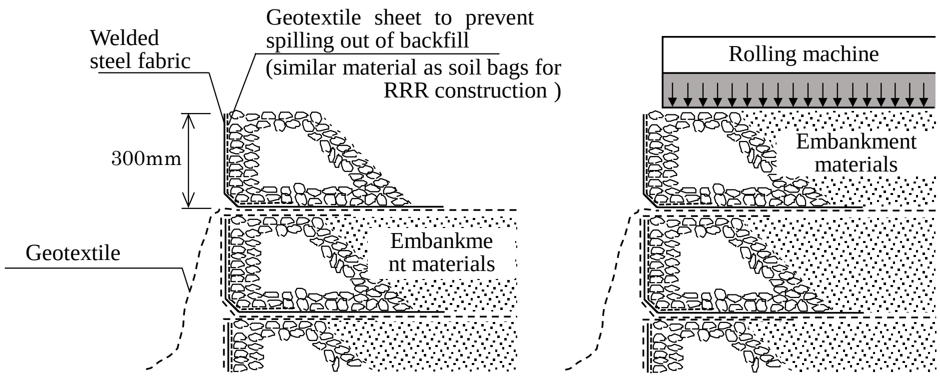


Figure 3.2.6-3 Temporary facing by welded steel fabric and simultaneous roller-compaction of embankment

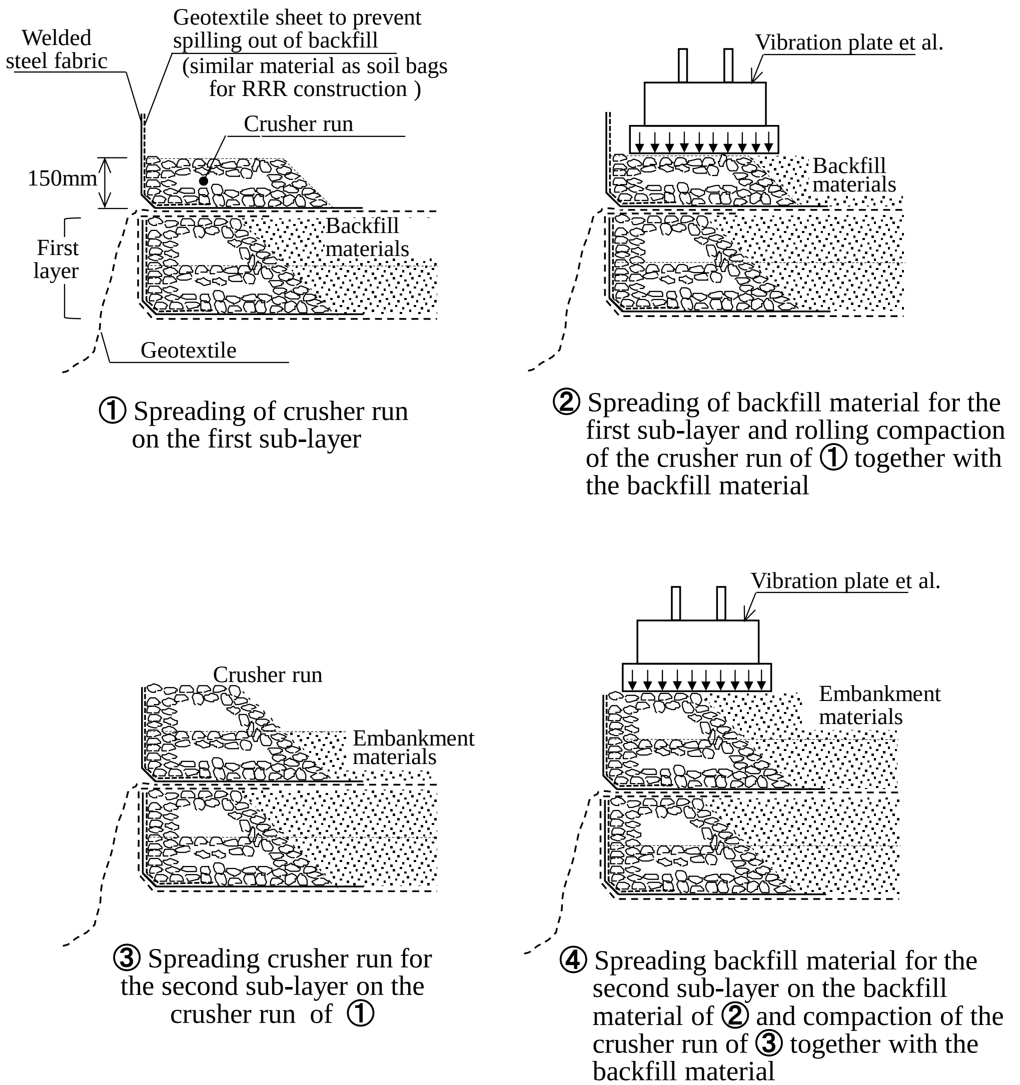


Figure 3.2.6-4 Temporary facing by welded steel fabric and simultaneous roller-compaction of backfill material
(in case of dividing one 300 mm-thick soil layer into two sublayers of 150 mm-thick each)

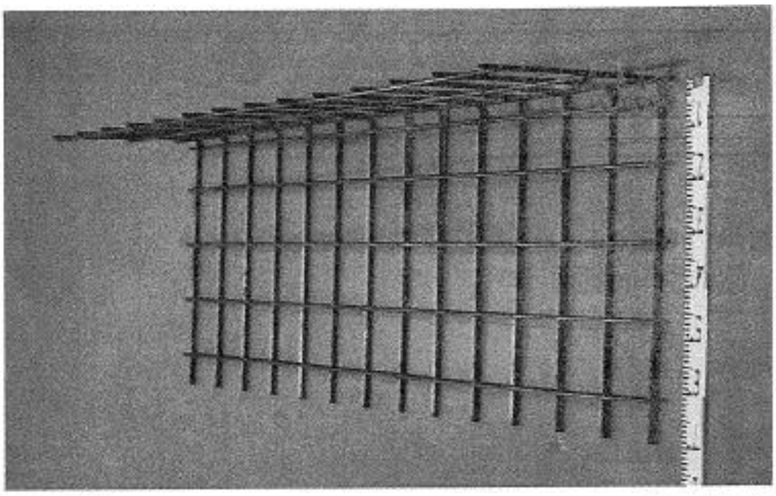


Photo 3.2.6-3 Welded steel fabric

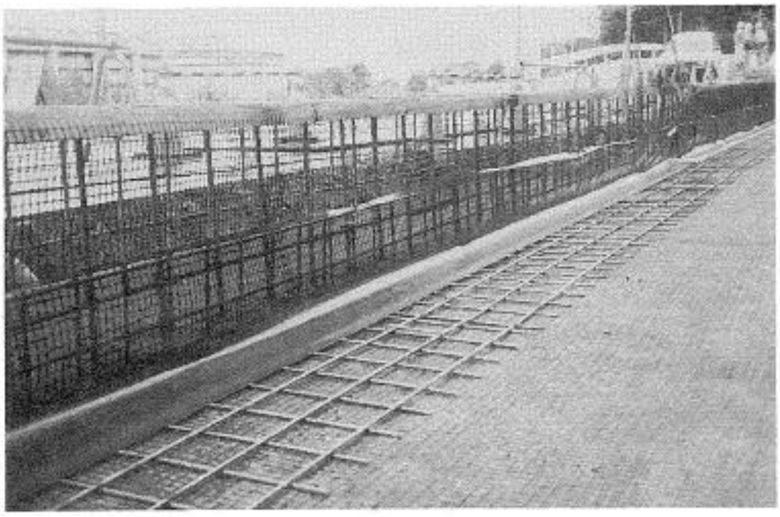


Photo 3.2.6-4 Layout of welded steel fabric

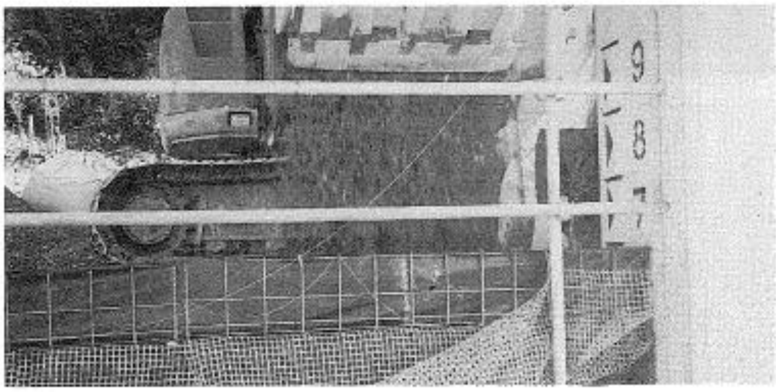


Photo 3.2.6-5 Attachment of geotextile sheet to prevent Spilling out of backfill

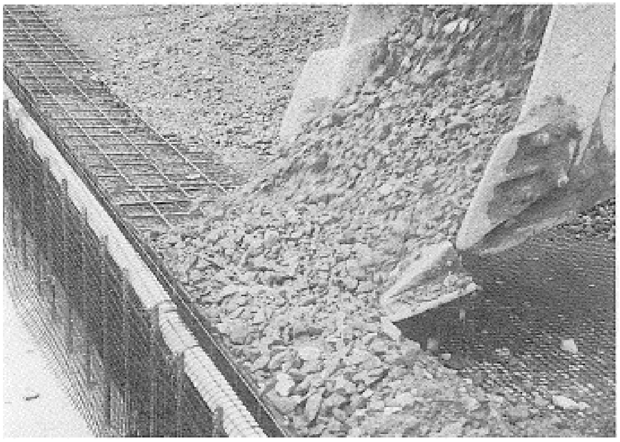


Photo 3.2.6-6 Throwing of crusher run

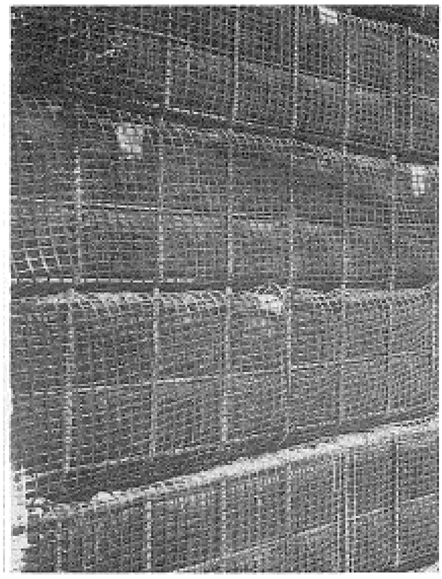
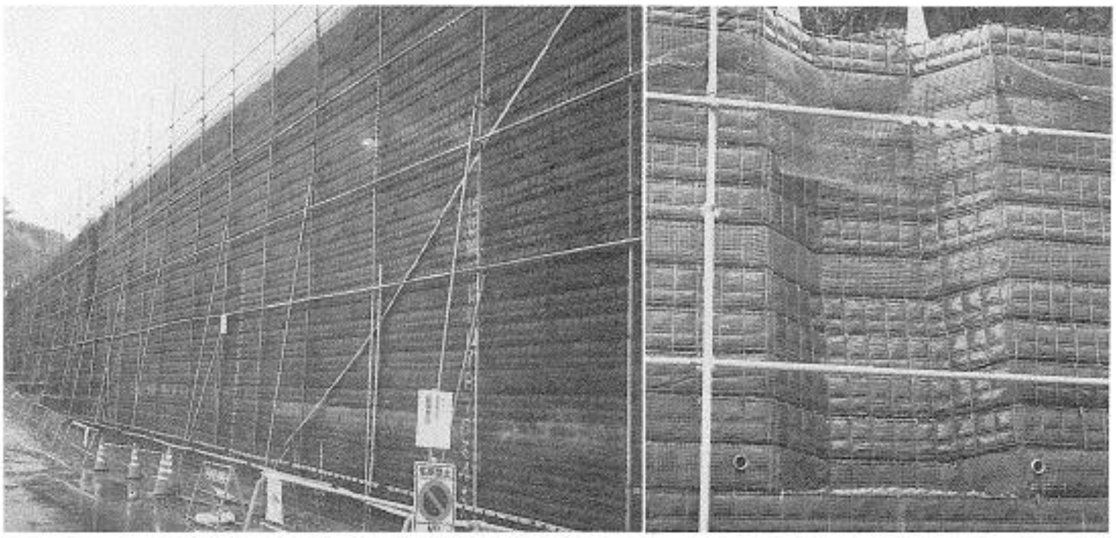


Photo 3.2.6-7 Welded steel fabric acting as temporary facing support



(1) Popular temporary facing support (2) Unique temporary facing support

Photo **3.2.6-8 Temporary facing support by welded steel fabric**

3.2.7 Spreading and Compaction of the Backfill Material

3.2.7-1 Spreading of the Backfill Material

The work of the spreading and leveling of the backfill material shall be carried out with the following matters adequately managed:

(1) Prior to spreading work, the backfill material to be used shall be confirmed.

(2) The spreading thickness shall be so determined that a specified degree of compaction and a specified finished thickness will be achieved.

(3) In carrying out spreading and leveling work, care must be taken that such work will not cause any dislocation and distortion or damage to the geotextile.

(4) Full safety management shall be conducted in carrying out the spreading and leveling work so that there will no fallout of workers and equipment from the wall face.

[Commentary]

With regard to (1) above:

It is important to confirm the quality of the backfill material to be used prior to the spreading work. The backfill materials that can be used for GRS RW shall be as shown in 2.4, Materials and Ground. If these soils are placed carefully under normal conditions, they will allow the specified degree of compaction to be achieved, involve only a small magnitude of settlement, cause only a low degree instantaneous and residual deformation that will occur due to the repetition of the application of traffic loads by running trains, and adequately ensure the stability of the reinforced embankment.

With regard to (2) above:

In the case of the reinforced embankment, the geotextile is laid on each layer of compacted backfill. Accordingly, it is needless to say that in spreading and leveling the backfill material, care must be taken not only to achieve the specified degree of compaction but also ensure that the thickness of the finished thickness of each backfill layer on which the geotextile is laid.

With regard to (3) above:

The work of spreading and roller-compacting the backfill material, should be done in a one-way direction starting from the end of one side in the direction in parallel with the wall face so that no bending deformation or looseness will not occur in the geotextile (Fig. 3.2.7-1). Furthermore, it is necessary to study the equipment to be used and the work sequence to meet the construction conditions.

The major factors in a possible occurrence of bending deformation in the geotextile during the above work are the use of a soil having a high water content as the backfill material and the careless use of heavy construction machinery, among other cases.

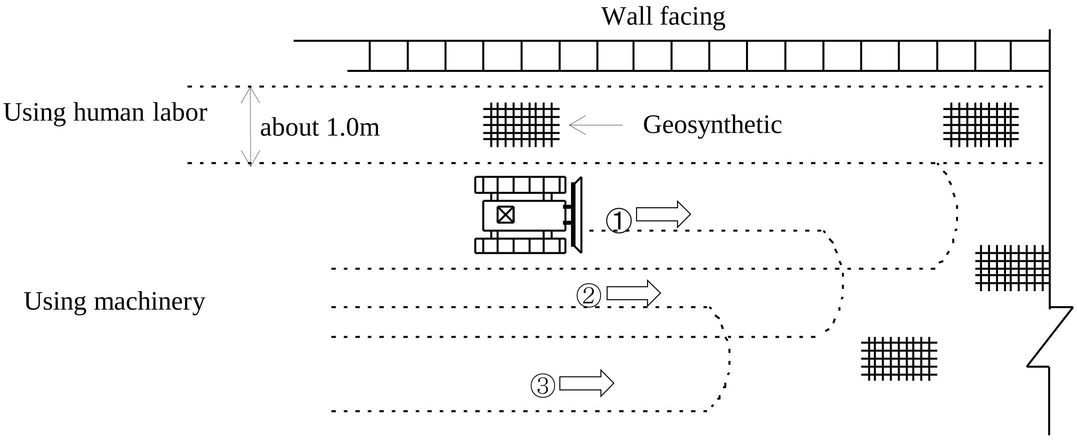


Figure 3.2.7-1 Spreading of backfill soil

The following are the precautions to be taken in using heavy machinery in the construction work:

i. The heavy machinery shall run in the direction parallel with the wall face.
If the work of spreading and leveling the soil is done toward the facing, it will cause a loosening of the geotextile and the swelling out of the temporary holding at the wall face (Fig. 3.2.7-2 (a)).

ii. The work shall be done from the wall face side step by step.
If the work of spreading and leveling the soil is done from the side far away from the wall face, it will cause a loosening of the geotextile and the swelling out of the temporary holding at the wall face (Fig. 3.2.7-2 (a)).

iii. Construction work near the wall face shall be done by human power.
Work with heavy machinery in the vicinity of the wall face will cause the collapse or swelling out of the temporary holding due to the dead weight of heavy machinery. For this reason, the basic principle is that any work within approximately 1.0 m from the wall face should be done by human power except in the case where safety in the work can be secured.

iv. Heavy machinery shall not be stopped or turned suddenly.
Generally, a sudden stop or turn of heavy machinery on the construction surface of the embankment shall be avoided because that will disturb the soil. In particular, a sudden stop or turn of heavy machinery shall not be made because that will disturb the soil in the location where the geotextile is laid and cause a distortion and dislocation with the geotextile.

With regard to (4) above:

The work of spreading and leveling the backfill material in the reinforced embankment involves human work near the wall face in a narrow place and heavy machinery is used in other places. These works are done in a complicated way. Under such circumstances, it is necessary to carry out adequate safety management so that heavy machinery does not approach the wall face so closely so that it may fall down from the wall face or a worker may fall down from the wall face.

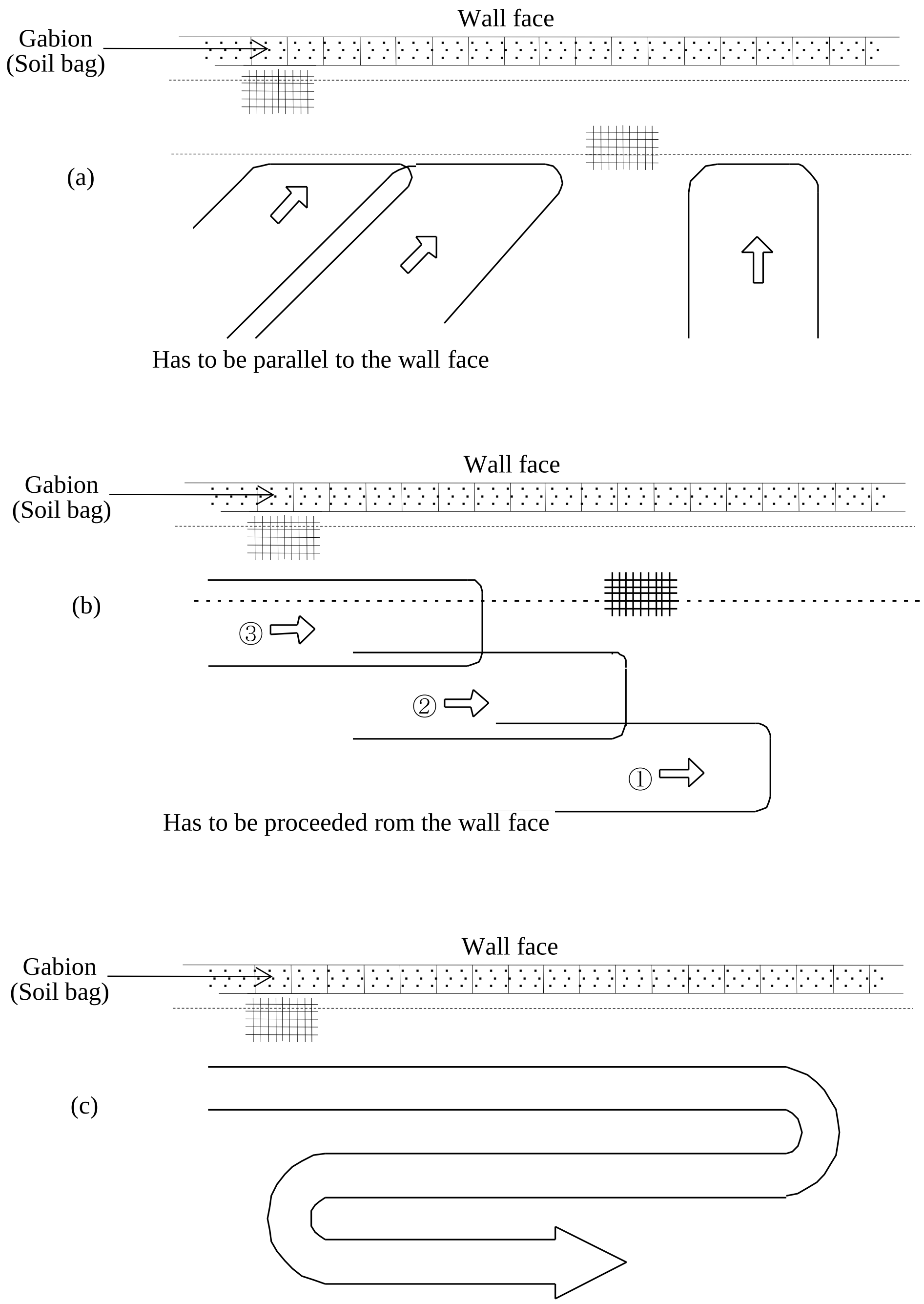


Figure 3.2.7-2 Operations to be avoided during soil spreading and roller-compaction using heavy machinery

3.2.7-2 Compaction of the Backfill Material

The degree of compaction of the backfill is closely related with the stability, durability, etc. of the GRS RW, and the compaction of the backfill shall be carried out with the following points being adequately managed:

(1) The compaction of backfill shall be so carried out that at least the specified degree of compaction will be achieved and the compacted backfill will be uniform.

(2) As for a compacting machine, proper models and combination thereof shall be selected that are unlikely to cause a disturbance or damage to the geotextile due to their operation and meet the construction work scale, work conditions, etc.

(3) It shall be ensured that compaction work will be finished by the time of the completion of work for the day. Also, if it is predicted that it will rain, proper measures to cope with the weather shall be taken.

(4) Work shall not be carried out at the time of rain.

[Commentary]

The degree of compaction of backfill is closely related with the stability, durability, etc. of the GRS RW, and it is required that the compaction of the backfill be carried out carefully. With general embankments, it is the standard principle that the construction of a test embankment is carried out prior to the construction of an actual embankment. In the case that the amount of earthwork is small (approximately 5,000 m^3 or less), it is generally accepted that the construction of a test embankment is carried out as part of the construction of an actual embankment (3.2.5 of the Design Standard for Earth Structures).

With regard to (1) above:

The required minimum degree of compaction is prescribed in 3.3.2, Management of Embankment Construction. In addition to this, the compacted backfill shall be uniform to achieve uniform distribution of loads, to prevent a decrease in the strength due to the effects of water including absorbed water, and to reduce compressive deformation due to surcharge loads, etc.

With regard to (2) above:

The compaction within a range of 1.0 m from the facing is typically carried out by using a vibration compactor and a tamping machine that are light in weight that is suitable for small-scale work so that the laid geotextile will not be disturbed.

Table 3.2.7-1 shows a general relationship between backfill type and construction equipment. The selection of the following machines should be avoided: i.e., the tamping roller that tends to apply pressure concentratedly, a towed-type machine that readily disturbs the geotextile when changing the direction, and a machine that will give a large horizontal force to the geotextile.

Table 3.2.7-1 Backfill materials and compactor types

Soil classification \ Compactor	Tire roller	Vibration roller
GW, G P	○	◎
G−M, G−C, G−V, GM, SW, S−M, S−C	◎	○
GC, SC, SM	◎	
S P	○	○

◎ : effective、 ○ : possible

<u>With regard to (3) above:</u>

The amount of work for one day shall be so planned that the work of compacting the backfill will be completed by the end of the day. If the backfill material has been spread and work is ended with the backfill material having been spread there, the backfill material will become soft due to the rainfall, etc. that may happen during the nighttime. This will cause a problem in the compaction work in the following day.

Furthermore, if it is expected at the time of the completion of the day's work that it will rain at later time, measures shall be taken to minimize the infiltration of rainwater into the backfill, including providing a drain gradient or drain ditch and covering the surface of the backfill with sheets, etc.

<u>With regard to (4) above:</u>

Under the RRR-B Construction Method, as in the case of ordinary embankment construction, the construction of an embankment shall not be carried out at the time of rainfall. If construction is carried out with the backfill material or embankment construction site being in the conditions unsuitable for work, that may result in insufficient compaction or the water content staying high, causing settlement after the completion of the embankment.

Therefore, in the case where work is started after rainfall, it is necessary to check to be certain that the water content of the backfill material and the trafficability of the construction site are suitable for work.

Photo 3.2.7-1　Compaction of backfill soil by manpower

Photo 3.2.7-2　Compaction of backfill soil by heavy compactor

3.2.8　RC Facing Work

After a reinforced embankment is completed to the specified height, a RC facing is constructed on the front side of the embankment.

[Commentary]

The RC facing work is designed primarily to resist the external pressures including the earth pressure acting on the wall and keep the stability of the reinforced embankment. The additional purpose is to protect the wall face of the reinforced embankment against external disturbances. The quality of the concrete and reinforcing steel rods that are used for the RC facing shall be in accordance with the Design Standard for Building Design (the section for plane concrete and the section for foundation structures and earth pressure resisting structures) as applied mutatis mutandis.

The construction of the RC facing shall be carried out in the same manner as for the concrete as stated in the regulations of the special specifications and the general common specifications. The general matters relating to the construction method shall be in accordance with the Concrete Specifications (Japan Society of Civil Engineers) as applied mutatis mutandis.

Generally, the works done as the wall facing work include:

(1) Temporary scaffolding assembly work
(2) Reinforcing steel rod assembly work
(3) Form work (including the case of using precast concrete panels for the RRR-B Construction Method)
(4) Concrete casting work

(1) Temporary scaffolding assembly work:

This work is for the assembly of scaffolding for the arrangement of concrete form, the casting of concrete, etc. in relation to the RC facing work. For the scaffolding, pipe scaffolding or prefabricated scaffolding is generally used (Fig. 3.2.8-1).

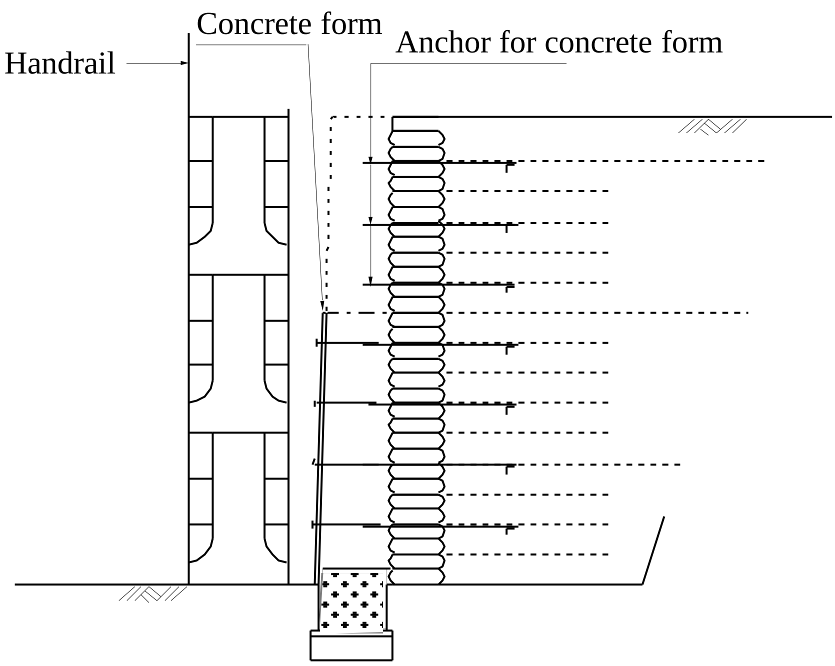


Figure 3.2.8-1 Typical example of scaffold

(2) Reinforcing steel rod assembly work

The basic principle of the wall facing work under the RRR-B Construction Method is to use cast-in-place steel-reinforced concrete.

(3) Form work:

To obtain the specified shape and dimensions of RC facing, the forms shall be adequately strong and be such that no distortion will occur at the time of concrete casting and after concrete casting, and there will be no leakage of mortar. Furthermore, since the RRR-B Construction Method is intended to ensure a high stability by adequately connecting the RC facing to the geotextile layers at the back face of the RC facing, back forms shall not be used in the wall facing work.

With regard to the form work for the reinforced embankment, the following points shall be taken into consideration:

(a) Method for setting up forms:

i) Case of using gravel bags for the temporary holding at the wall face:

Since no back form is used, it becomes necessary to adopt a method for fixing forms. Figures. 3.2.8-2 and 3.2.8-3 give an example of the form fixing method. In this example, form anchors with an equal angle steel (L-65 or so) welded to the rear end of the steel rod (Φ: 16 mm or so) were set up inside the embankment, and form separators were joined to them by welding. In setting up the form anchors, the surface of the backfill that has been roller-compacted is excavated carefully in such way that the geotextile to be laid above the form anchors will not be damaged, and the form anchors are buried with the equal angle steel lying on the bottom side of the geotextile. The intervals of setting-up the form anchors shall be generally every two layers (approximately 600 mm).

Further, there will be an occurrence of settlement due to the embankment. The amount of settlement will differ depending on the strength of the supporting ground. For this reason, the form anchors set up in the embankment will also subside and get dislocated from the original position. The, it may become difficult or impossible to weld the separators to the form anchors. To alleviate this potential problem, it is preferable to attach vertical and also horizontal members of equal angle steel (L-50 or so) to the front end of the form anchors as illustrated in Fig. 3.2.8-4 and weld the form separators to the horizontal equal angle steel.

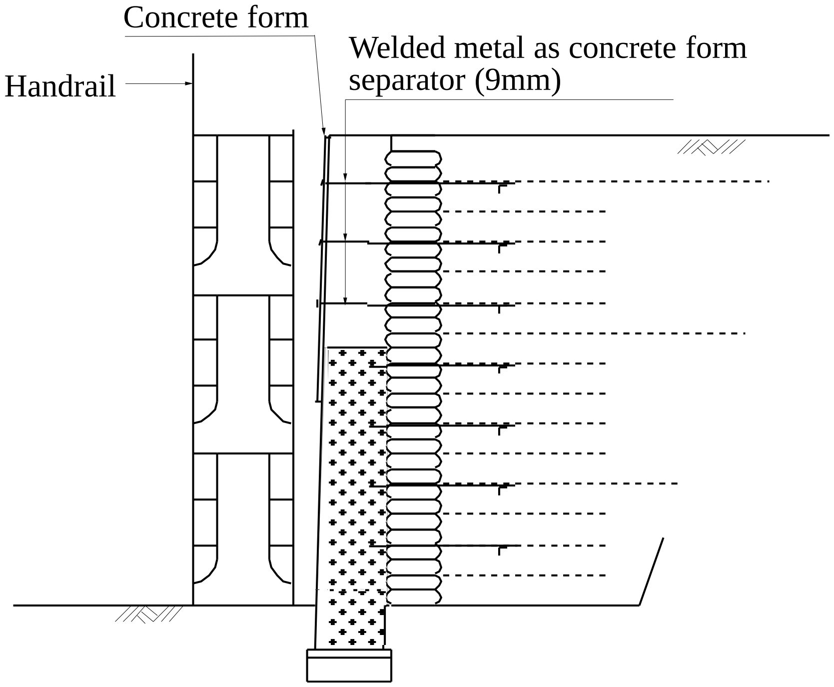


Figure 3.2.8-2 Typical fixing of concrete form for the facing construction by using sandbags

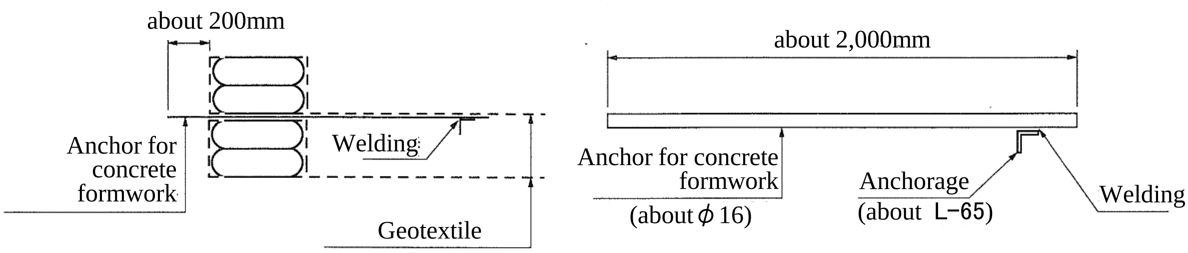


Figure 3.2.8-3 Details of the anchor for concrete formwork

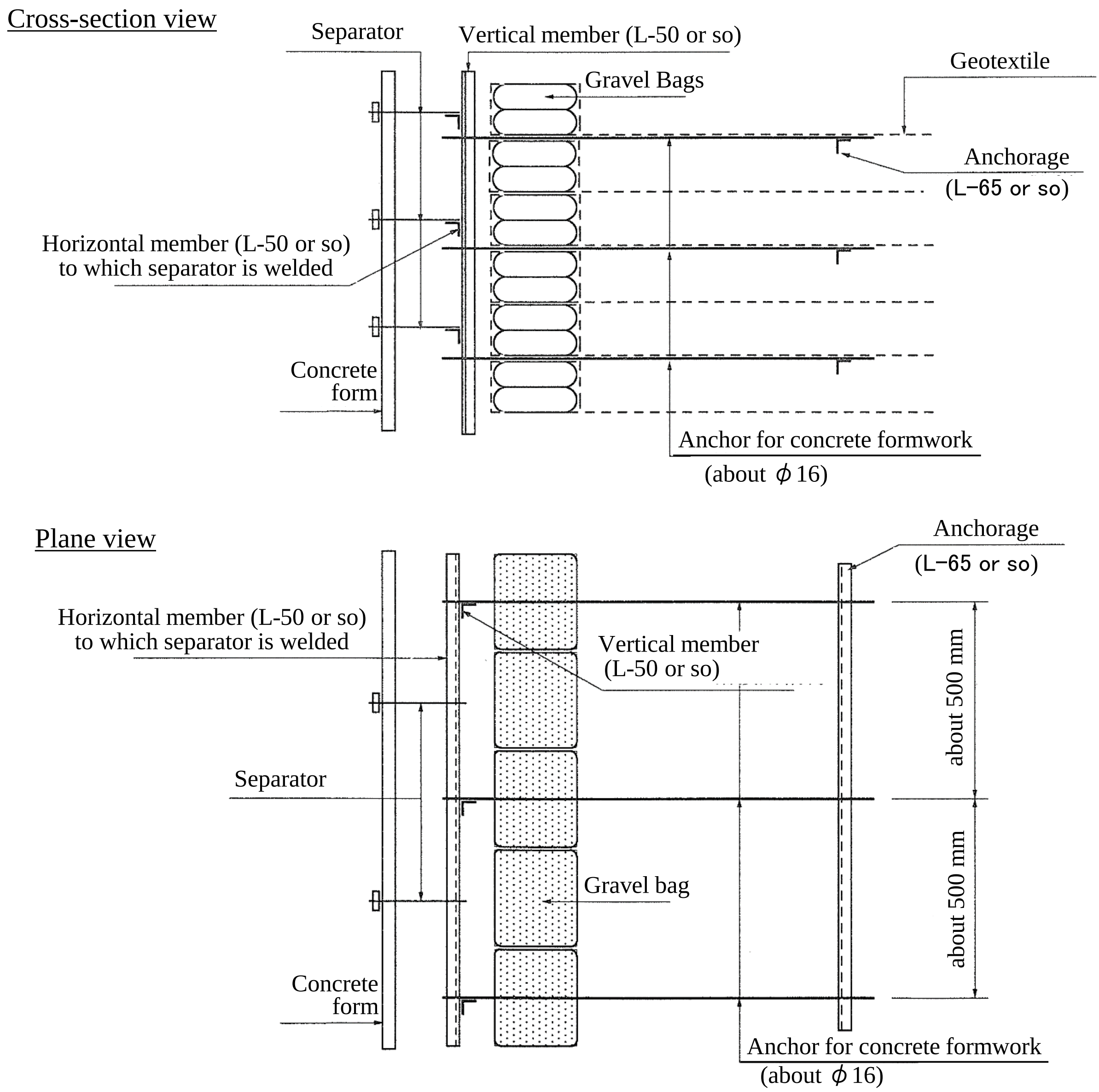


Figure 3.2.8-4 Details of installing concrete form for the facing construction

ii) Case of using welded steel fabric for the temporary holding at the wall face:
In the case of using welded steel fabric for the temporary holding, it is possible to omit the conventional form anchor by using a fixing metal fitting. As for this fixing method, a fixing metal fitting is fixed to one piece (D10) of the rising part of the welded steel fabric and at the same time fixed by welding to the equal angle steel (L-40 or so). The form separator is also fixed by welding to the vertically arranged member of equal angle steel. However, another method must be studied if a precast concrete panel is adopted in place of the form. (Refer to (5) Precast Concrete Panel for the RRR-B Construction Method.)

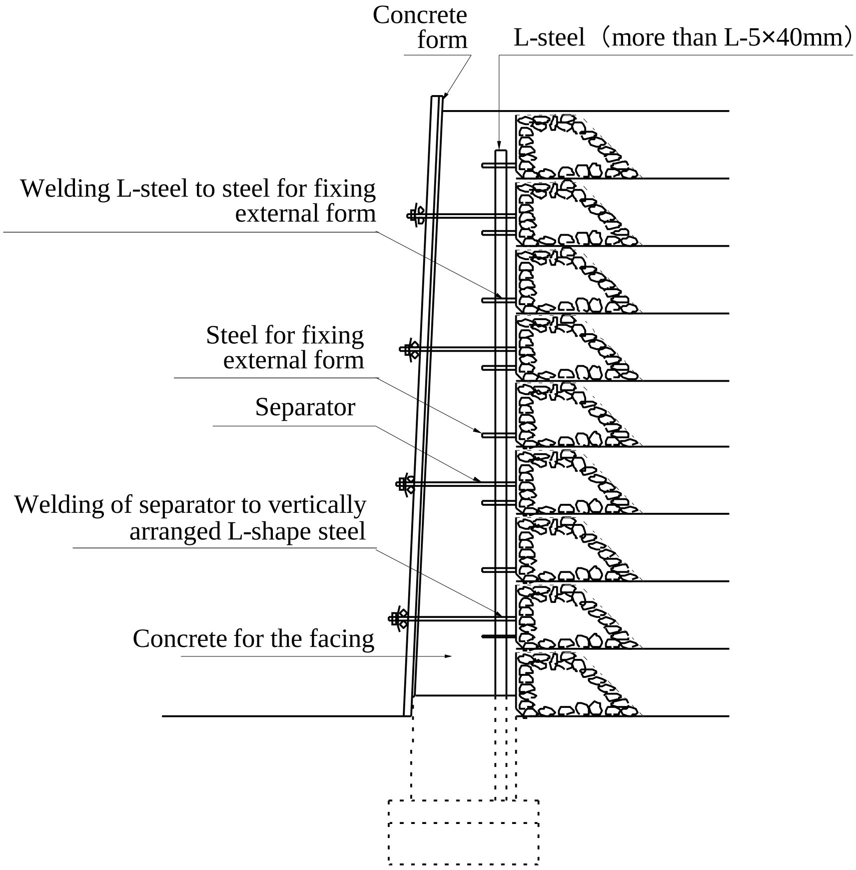


Figure 3.2.8-5 Example of the method to fix concrete form for the facing construction using welded steel fabric

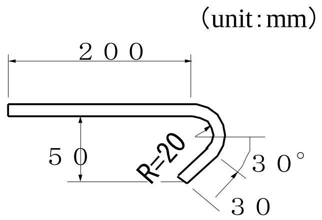


Figure 3.2.8-6 Shape of steel for fixing external form in case of using welded steel fabric

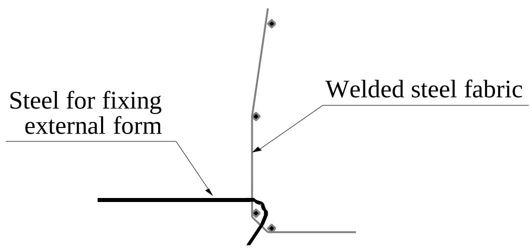


Figure 3.2.8-7 Example of the method to arrange steel for fixing external form to welded steel fabric

(b) Method for setting up forms:

Generally, a plywood form, metal form, etc. are used for the material of form. It is also possible to use a slide form and a large form. In this case, cranes and other machines are used, and they often remain at the site at all times. For this reason, in this case, it is necessary to take special care for safety and make an overall comparative study at the stage of construction planning.

If there are any particular instructions issued from an aesthetic point of view, approval has to be sought for the form material (decorative forms, etc.) Also, it is necessary to confirm the method of using it.
Further, there is also a method of using a precast concrete panel in place of the form, making it a part of the RC facing, for the purpose of labor saving, safety and cost reduction. (Refer to (5) Precast Concrete Panel for the RRR-B Construction Method.)

Photo 3.2.8-1 Example of scaffold frame

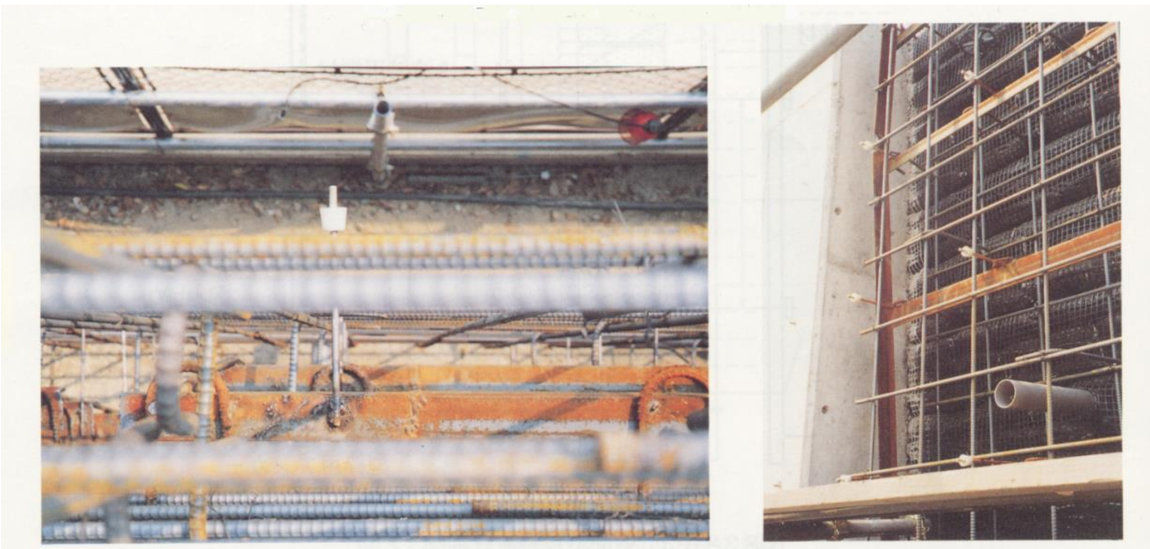


Photo 3.2.8-2 Formwork (Example of setting separators)

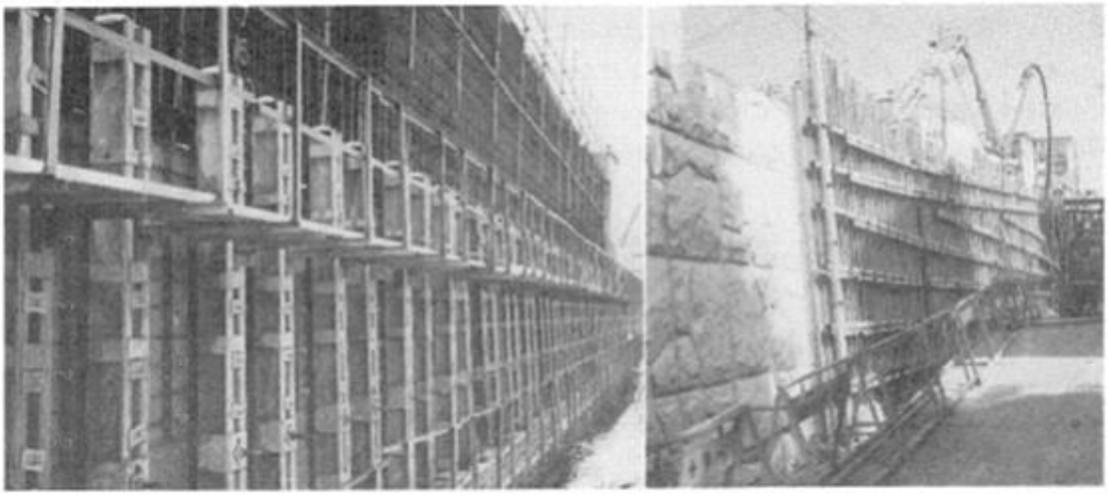


Photo 3.2.8-3　Form installation

(4) Concrete casting work:

Concrete casting shall be carried out by following the general practice of concrete casting. In particular, the following points shall be kept in mind in concrete casting:

i. In concrete casting, adequate care shall be taken that the buried objects such as drain pipes and fixing materials will not be dislocated or damaged.

ii. Laitance treatment shall be carried out securely at the locations of the construction joint surface of concrete.

   As to the laitance treatment method, the high-pressure water jet method is generally used. It is necessary to choose an appropriate time and method.

iii. The RC facing shall be provided with expansion joints (Refer to the section of Structural Details of Chapter 2.).

   In order to ensure that the ground settlement due to the residual deformation due to consolidation will not have an adverse effect on the completed RC facing, expansion joints are provided. The intervals of expansion joints are set at 20 m or less, normally 10 to 15 m. If there is a longitudinal slope in the supporting ground or an electric pole foundation is installed in the RC facing, an adequate investigation should be made as to the intervals of expansion joints on the basis of design philosophy.

   Generally, with a relatively massive wall-like structure, thermal cracks tend to occur, and it may become necessary to employ summertime concrete measures during summertime construction in some cases.

   With regard to cracks, it is also effective to take measures to use crack control reinforcement bars, crack-inducing joints, etc.

iv. As for the time of casting concrete for the facing, the approval of the supervisor shall be obtained for the time through consultation with the supervisor.

When there are any concerns about any effects of the residual settlement of the supporting ground and the reinforced embankment, a study shall be made as to effective measures, such as a change of the time of casting concrete on the wall face.

As to the sequence of casting concrete, it is preferable that concrete be cast from the lower section of each block of the facing.

(5) Precast concrete panel for the RRR-B Construction Method:

Under the RRR-B Construction Method, fresh concrete must be cast without setting up any back form to integrate the geotextile layers and the RC facing into one. For this reason, in some cases, setting up of the concrete form may become difficult.

Under this circumstance, there is the precast concrete panel for the RRR-B Construction Method available to be used as a substitute for the form and at the same time be made a part of the RC facing for the sake of labor saving, safety and cost reduction.

Figs. 3.2.8-8 to 3.2.8-11 show the general structure diagram of the standard panel (2,000 mm x 1,000 mm x 125 mm, 587 kg/panel).

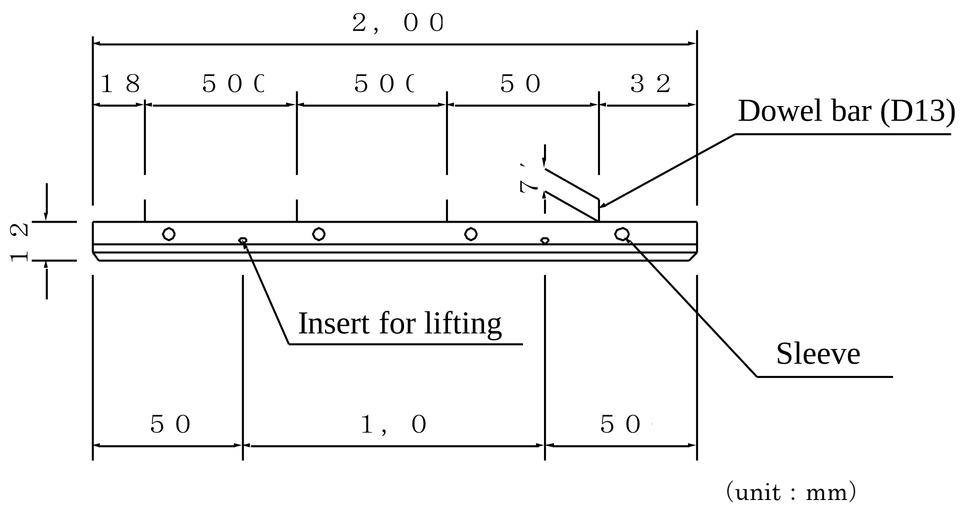


Figure 3.2.8-8 Plane view of RRR-panel (Standard panel)

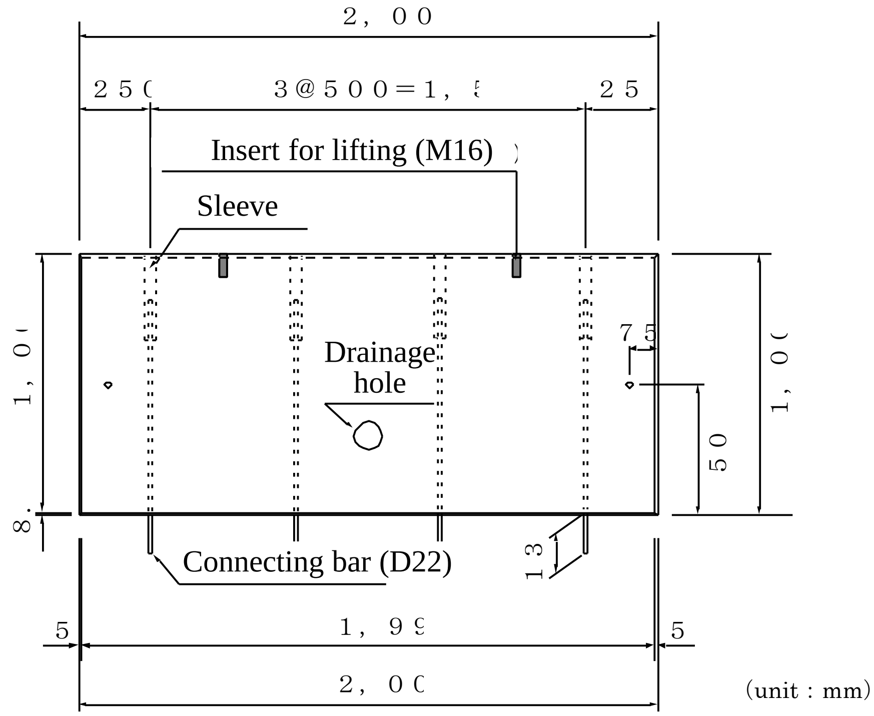


Figure 3.2.8-9　Front view of RRR-panel (Standard panel)

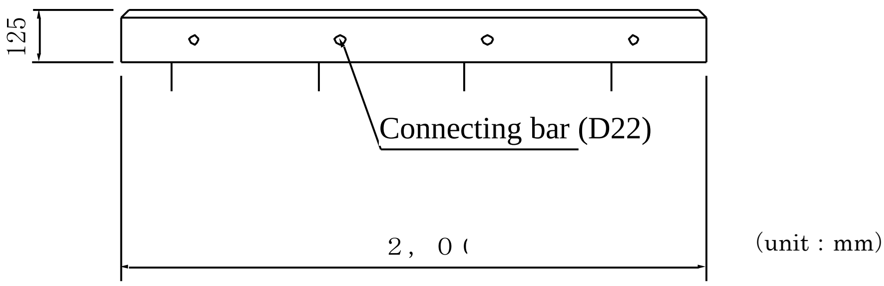


Figure 3.2.8-10　Bottom view of RRR-panel (Standard panel)

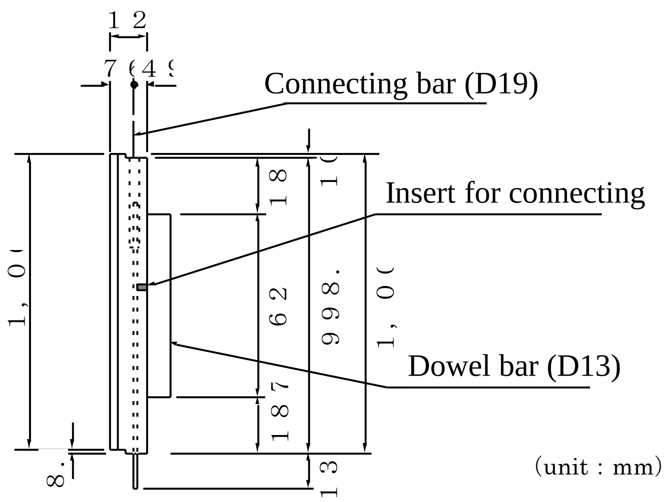


Figure 3.2.8-11　Cross-sectional view of RRR-panel (Standard panel)

Photo 3.2.8-4　Installation of RRR-panel

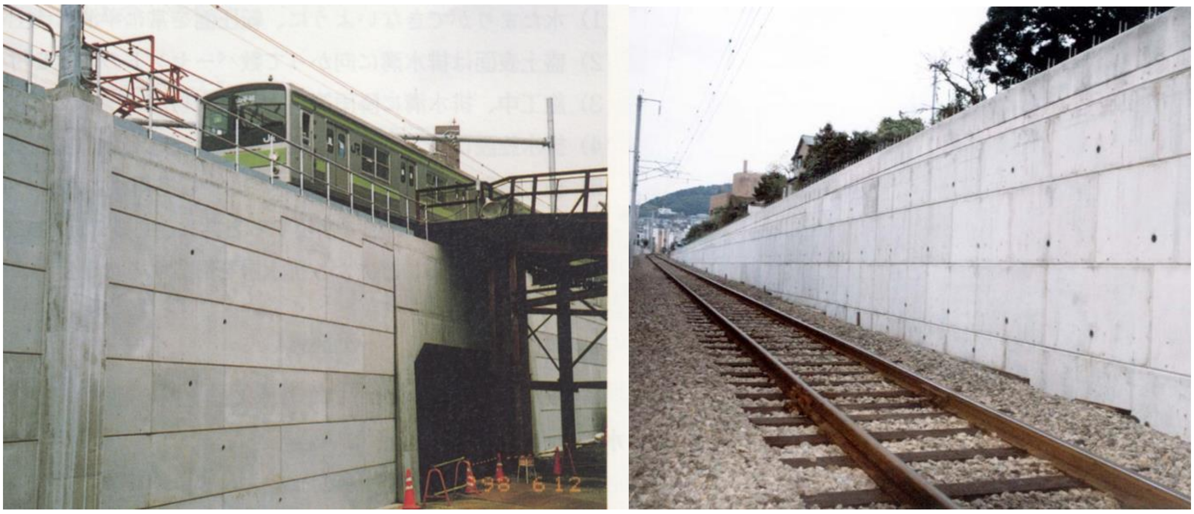


Photo 3.2.8-5　GRS RW constructed by using RRR-panel

3.2.9　Drainage Work

For the GRS RW, adequate drainage measures relating to the following and other points shall be taken, taking into consideration the conditions during the construction and after the completion thereof:

(1) Surface drainage during the construction work

(2) Drainage in the GRS RW

(3) Drainage in the outer peripheral area of the GRS RW

[Commentary]

Drainage work is one of the types of work important for ensuring the safety and workability of the GRS RW similarly as in the case of general embankments.

The embankment is reinforced by the friction between the geotextile and the soil. As a result, when the pore water pressure in the soil rises due to infiltrating water such as rainwater, the frictional force at the interface between the geotextile and the soil will decrease and the embankment will tend to become unstable. For this reason, it is necessary to prevent rainwater, etc. from infiltrating into the embankment and drain the infiltrating water from the embankment.

With regard to (1) above:

Water coming from rainfall and snowfall turns the embankment surface muddy, causing a decline in workability, and causes the erosion and scouring of the slope surface. In particular, backfill materials (sand, volcanic soil, etc.) having good permeability is greatly eroded or scoured due to a concentrated flow of rainwater, etc.

With embankments using the geotextile, compared with general embankments, it is possible to reduce damage due to those phenomena and improve the stability and workability. Yet, it is necessary to carry out surface drainage in the same manner as in the case of general embankments. Particularly in the case where there is a backfill material in a state in which it has been spread and has not been compacted, it is necessary to take such actions as covering the surface with waterproof sheets to prevent rainwater from infiltrating into the backfill at the time of rain.

The general precautions to be taken during the construction work for GRS RW are as follows:

i. It shall be ensured that the compacted surface will be finished smoothly at all times so that no pool of water will be created.

ii. An inclination of several percent toward the drain ditch shall be given to the embankment surface so that there will be satisfactory drainage.

iii. If flow deposits due to rainfall, etc. accumulate in the drain ditch during the construction work, they shall be removed promptly.

iv. Drain facilities shall be installed as early as possible, starting from the section which is ready for installation.

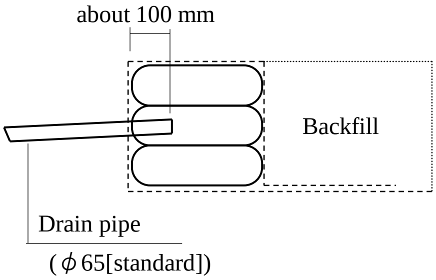
v. In the case where the construction time falls in a rainy season or a backfill material having a high water content is unavoidably used, the soil shall be aerated as far as possible before it is used, and it is preferable to form a drainage layer inside the embankment by laying a filtering material or a nonwoven geotextile in the embankment at an appropriate vertical spacing.

With regard to (2) above:

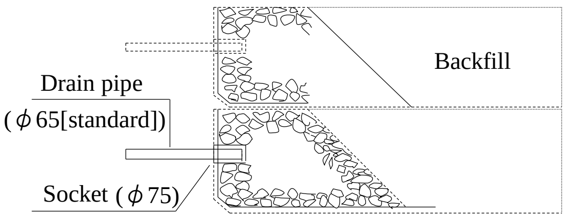
If the water having infiltrated into the embankment due to rainfall, etc. is not drained promptly, the pore water pressure in the embankment will rise. In order to prevent this, a proper drainage work must be provided.

i. Water drain pipe 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 draw-out prevention material (thickness: 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.



(a) Case of the facing construction by using gravel bags (see "2.5 Structural Details")



(b) Case of the facing construction by using welded steel fabric

Figure 3.2.9-1 Typical arrangement of drain pipe

Photo 3.2.9 Installation of drain pipes

ii. In the case of constructing a reinforced embankment using cohesive soil, a geotextile having a drainage function is generally used for drainage in the embankment. In the case of not using such geotextile, if cohesive soil is used, a nonwoven geotextile, etc. shall be additionally laid over the full length both in the section of basic geotextile (i.e., geogrid) at a vertical interval of 0.3 m and in the section in which long layers of geotextile (i.e., geogrid) are laid at a vertical interval of 1.5 m.

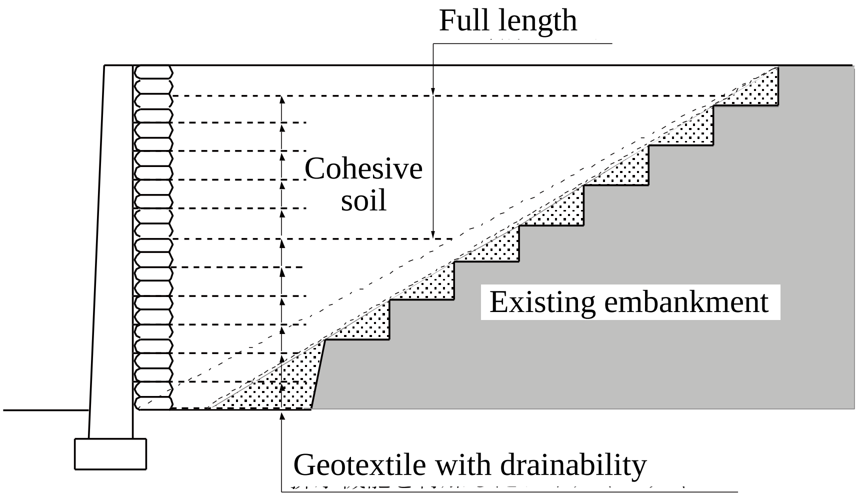


Figure 3.2.9-2 Cross section view of RRR-B structure with cohesive backfill soil

iii. With an expanded embankment added to an existing embankment, necessary drainage measures, including the provision of a drain gutter at the boundary with the existing embankment, shall be taken depending on the conditions of the site

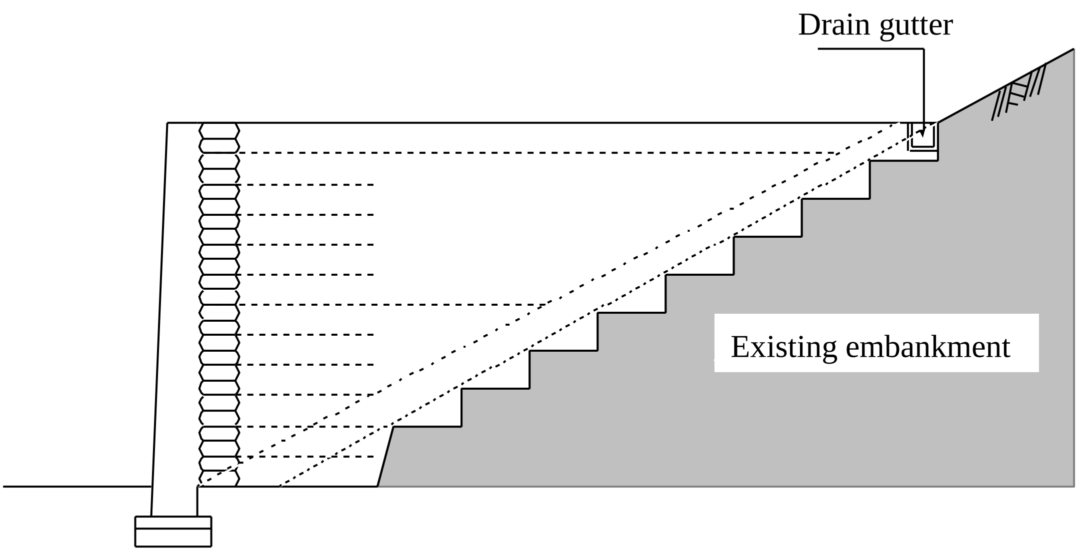


Figure 3.2.9-3 Example of drain gutter when widening the embankment

With regard to (3) above:

In principle, a drain gutter shall be made immediately in front of the wall face. The purpose of this ditch is to dispose of rainwater and the water discharged from the back face of the facing and to prevent the scouring of the embedded depth section due to the water running along the front face of the foundation for the facing from the peripheral area of the GRS RW. Generally, a reinforced concrete U shape (JIS A 5305) is used for such drain gutter.

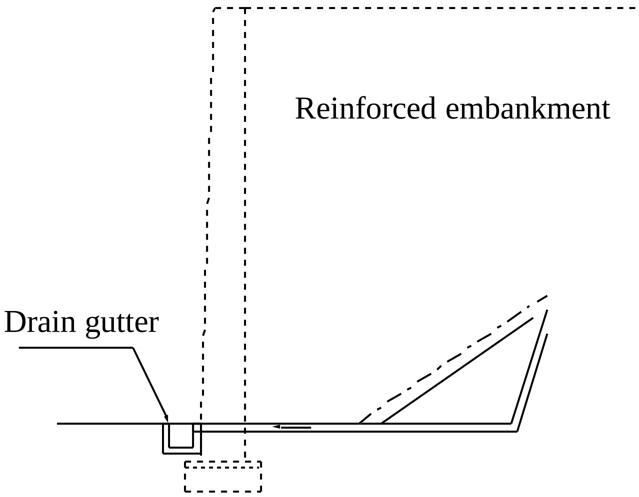


Figure 3.2.9-4 Example of drain gutter in front of the facing

3.3 Construction Management

3.3.1 Construction Management – General

The specified construction shall be carried out safely and smoothly within the construction period, and adequate construction management shall be conducted to achieve the quality and shape as shown in the design documents.

[Commentary]

Construction management shall be conducted to confirm that the construction is being carried out by the work procedure as described above in accordance with the work standards as prescribed by the construction plan by using backfill materials and other materials that are shown in the design documents and the specifications and that the quality and shape that are shown in the design documents have been achieved.

Therefore, during the construction, a comparison shall be made between the plan and the design at all times. If there is a discrepancy between them, an improvement must be made by an appropriate method.

3.3.2 Embankment Construction Management

In embankment construction work for the geosynthetic-reinforced soil retaining wall (GRS RW), the backfill material shall be spread and compacted in accordance with the Design Standard for Earth Structures, and embankment construction work shall in principle be managed in accordance with the construction management procedure that is shown in 3.2.3 of the Design Standard for Earth Structures.

[Commentary]

1) The following points are the significant consequences of good compaction of an embankment:
   (a) Securement of stability:
      - Compaction will reduce the void ratio in soil, lower the water permeability, and reduce the extent of the softening and swelling of the soil due to the infiltration of water to make the soil stable.
      - Compaction will give strength properties that are necessary for the backfill to support the dead weight, train weight, etc.
   (b) Decrease in the amount of settlement:
      - Compaction will reduce the compressive settlement of the embankment itself that will have an adverse effect on the running of trains in service.
   (c) Securement of roadbed strength:
      - Compaction will give roadbed strength required of the roadbed that supports train loads.

As shown in 1.1.3, Definitions of Terms, the section to a depth of 3 m from the top surface of constructed backfill is called the upper embankment section, and the section below that is called the lower embankment section. The upper embankment section that is greatly affected by train loads is considered to be a section to a depth of 3 m down from the top of the constructed backfill base (excluding the roadbed portion), and the backfill materials and the degree of compaction that are used for the upper embankment section are different from those for the lower embankment section.

2) Soil compaction controll:

The soil compaction control for a given earthwork project should be specified so that the required performance of concerned geotechnical structures can be ensured while taking into account into account the local conditions, including local design codes to be applied to the concerned project, locally available fill materials and construction machines available at reasonable cost, local weather conditions, local construction restrictions etc. In the following, typical specifications for railway structures are shown.

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 %. The field dry density, ρ_d, of compacted soil is measured by the sand cone method or the radio isotope (RI) or another appropriate method. The maximum dry density, $[\rho_{dmax}]_{4.5Ec}$, is obtained by the standard laboratory compaction tests using 4.5Ec. It may be relevant to modify these specifications described above when it is deemed adequate to do so for proper compaction quality assurance under given local conditions.

The compacted state and the stiffness of compacted soil may be evaluated based on the coefficient of vertical subgrade reaction (K_{30}) measured by the field plate loading test (PLT) using a 30 cm-diameter plate. The value of K_{30} can be obtained by converting the coefficient $K_{P.FWD}$ evaluated in a much faster manner by the portable Falling Weight Deflectometer (P.FWD) test.

When the compacted state and the stiffness of compacted soil is evaluated based on K_{30} values, the following caution is relevant. In compaction at a certain compaction energy level (CEL) in the field, as the water content, w, of compacted fill becomes higher than the w_{opt} value corresponding to the field CEL (i.e., as the moisture state becomes wetter than the optimum), typically in a rainy season, the compacted dry density, ρ_d, decreases while K_{30}

also decreases. So, it is feasible to ensure that the compacted state is satisfactory by not allowing field K_{30} values lower than a specified lower bound. On the other hand, as w becomes lower than the w_{opt} value (i.e., as the moisture state becomes drier than the optimum), typically in a dry season, ρ_d decreases while K_{30} increases. In this case, a higher K_{30} value means a lower ρ_d value. So, it is not feasible to ensure that the compacted state is satisfactory by not allowing field K_{30} values lower than a specified lower bound. Besides, the compacted soil may become wet or saturated sometimes during a long lifecycle span. The K_{30} value of soil compacted drier than the optimum may largely decrease upon wetting or saturation. So, it is not feasible to ensure that the compacted states and/or the stiffness of compacted soil under design conditions are satisfactory based on measured field K_{30} values only, but it is necessary to evaluate the compacted (ρ_d, w) states and/or the stiffness of compacted soil under design conditions.

3) Case of rock fragments:
In the case where rock fragments are used for the backfill material, it will be difficult to control the degree of compaction on the basis of the dry density because the particle size of rock fragments may be too large. For this reason, the basic principle for compaction control is to follow the construction method specifications.

3.3.3 Management of the Geotextile

The geotextile, being integrated with the embankment for a long time, requires adequate strength. For this reason, the geotextile needs to be managed with adequate care so that it will not rupture or deteriorate during construction.

[Commentary]

The geotextile is fixed to the RC facing that are constructed in front of the reinforced embankment and functions as the reinforcement of the embankment for a long time.

For this reason, the geotextile needs to be managed with adequate care by keeping it away from the UV light of direct sunshine during storage and ensuring that it will not be damaged due to bending, so that its strength will not decrease due to rupture or deterioration.

Furthermore, in the execution of construction, the geotextile needs to be managed with adequate care so that it will not be ruptured by sharp corners of rolling stone or crushed stone, among other things.

3.3.4 Management of Facing Work

The RC facing under the RRR-B Construction Method protects the front face of the reinforced embankment and forms the major component of GRS RW in integration with the embankment on the back face side. For this reason, facing work needs to be managed so that there will be no deformation in the RC facing, etc. due to a differential settlement in the embankment on the back face side or the existing supporting ground relative to the RC facing.

[Commentary]

Since the RC facing in front of the reinforced embankment is so constructed that it is integrated to the geotextile layers and the temporary holding (gravel bags, welded wire mesh, etc.), no back concrete forms are used.

For this reason, the backfill on the back face side must be adequately compacted so that there will be no differential settlement between the RC facing and the embankment on the back face side.

In the case where the existing supporting ground is soft, it is necessary to wait for the supporting ground to become stable before constructing the RC facing.

Furthermore, in some cases, any devices for investigating the deformation/displacement of the RC facing, etc. may be buried or attached, and measurement is taken, according instructions given as required.

3.3.5 Safety Management

In safety management, it is necessary to take account of safety for cars and trains in the work for a line open to traffic as well as the safety of work and the third parties.

[Commentary]

In the case of carrying out work in the vicinity of a line open to traffic, consultation shall be held about construction in the neighboring area, and safety personnel (qualified persons) shall be set.

Furthermore, during the roller-compaction of the backfill, appropriate measures shall be taken to prevent any equipment to fall down from the GRS RW under construction.

References:

1) “Standard Instructions Concerning Safety in Work in the Vicinity of a Line Open to Traffic” (for conventional and Shinkansen lines), Japan Railway Civil Engineering Association (March 1999)
2) “Guideline for Design and Construction in the Neighboring Area”, Railway Technical Research Institute (September 1987)
3) “Guideline for Measures for Preventing Public Disasters Due to Construction Work” (for Civil Engineering Work), Taisei-Shuppan Co. (February 1993)

4) “Guideline for Safe Execution of Civil Engineering Work”, Japan Construction Engineers’ Association (May 1998)

Further, if any of the above publications is revised, the latest edition shall prevail