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STRESS-CONFINEMENT EFFECT OF NONWOVEN GEOTEXTILE ON DESIGN OF REINFORCED SOIL RETAINING WALL

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ABSTRACT

The design implication of stress-confinement effect of nonwoven geotextile is addressed. The unconfined and confined strengths of a selected needle-punched nonwoven geotextile are used to conduct a comparative design of a granular soil retaining wall based on a limit equilibrium approach. A higher wall may be allowed when considering the confined strength as compared to the unconfined strength. For a selected wall height, confined strength allows for fewer geotextile layers when compared to that designed using unconfined strength. It is recommended that stress-confinement test procedure should be standardized so that confinement effect of some nonwoven geotextiles may be incorporated into an individual wall design procedure.

Key words: confined strength, limit equilibrium method, nonwoven geotextile, reinforced soil structure, stress-confinement effect (**IGC**: E0/E5/E6)

INTRODUCTION

Geosynthetics are widely used to tensile reinforce walls and slopes. Many experimental studies have been conducted to investigate their mechanical and interaction properties with soils. It is well known that when a needle-punched nonwoven geotextile is subjected to stress confinement, similar to the conditions embedded in the soil, it exhibits an improved performance in terms of stiffness and strength. This is attributed to an increase in the frictional interaction between the fibers as a result of increased normal stress. Performance of many earliest geosynthetic-reinforced soil walls, such as those at the Glenwood Canyon (Wu et al., 1994), are reported to be better than predicted. Stress-confinement effect, among others, might have played a role in rendering good performance.

The current geosynthetic testing standard, such as the grab method (ASTM D 4632) and the wide-width strip method (ASTM D 4595), do not specifically account for such effect. Several specially designed devices have been proposed for measuring intrinsic confined tensile properties of nonwoven geotextiles. For example, the in-soil test apparatus (McGown et al., 1982), the zero span test (Christopher et al., 1986), the membrane-confinement test (Tatsuoka and Yamauchi, 1986), the pullout/direct shear hybrid device (Leshchinsky and Field, 1987), the cylindrical soil-confinement test (Wu, 1991), and the plane strain confinement test (Ling et al., 1991). A brief review of these devices, including their capabilities and limitations, may be found in Ling et al. (1992). Although these devices differ slightly from one other, experimental results led to a similar conclusion indicating that stiffness and strength of nonwoven geotextile are increased under stress confinement.

The plane strain device (Ling et al., 1992) is suitable for conducting confinement tests using rubber membrane or soil as a confining medium. A schematic sketch of this device is shown in Fig. 1(a). The testing device was housed in a large-scale triaxial testing apparatus. Nonwoven geotextile specimen was reinforced at two ends using epoxy and installed to the device (Fig. 1(b)). A flexible latex membrane can be used to confine the geotextile specimen in lieu of soil, as shown in Fig. 1(c). In the confinement tests, confining pressure was applied using suction through a plastic tubing penetrating the membrane. Through a series of confinement tests conducted on different nonwoven geotextiles, it was concluded that membrane can be used effectively for replacing soil as confinement material, and thus greatly simplify the testing procedure. It also led to the conclusion that there is negligible confinement effect in the heat-bonded geotextile due to its compact structure.

Figure 2 shows the test results of a needle-punched nonwoven geotextile confined with a rubber membrane un-

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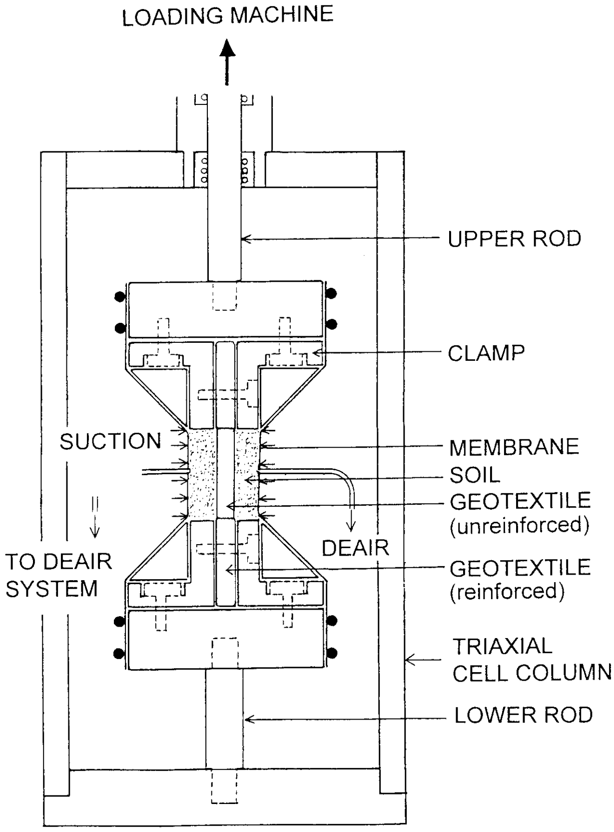


Fig. 1(a). Plane strain confinement test

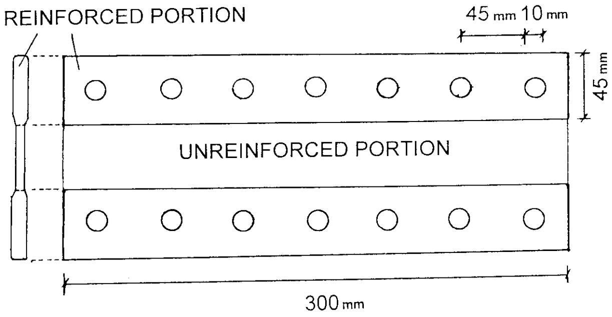
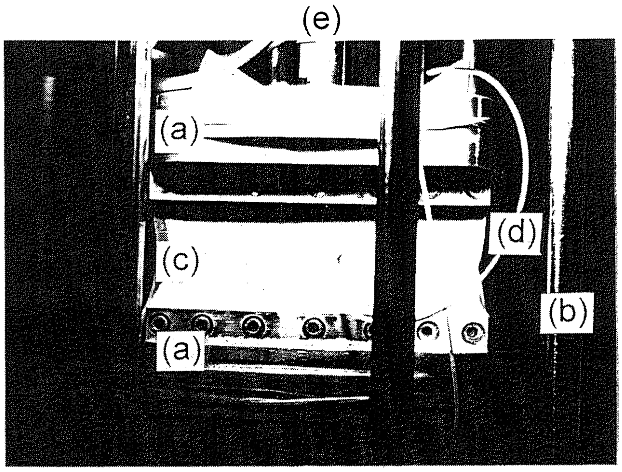


Fig. 1(b). Geotextile specimen



(a) CLAMP
(b) TRIAXIAL CELL COLUMN
(c) GEOTEXTILE SPECIMEN
(d) DEAIR TUBE
(e) UPPER ROD

Fig. 1(c). Membrane-confinement test

der different pressure levels. This needle-punched geotextile is manufactured from polyester fibers having a mass per unit area of 0.36 kg/m^2. The test results are for specimen of aspect ratio of 2 (width = 20 cm, length = 10 cm). Confinement effect is obtained for this geotextile. It is seen that at a confining stress of 75 kPa, corresponding to a geotextile sheet embedded under 4 to 4.5 m of soil, the geotextile strength is nearly doubled while the initial stiffness is tripled.

The last few years witnessed additional experimental studies highlighting stress-confinement effect of different geotextiles, for example, Ballegeer and Wu (1993), Cazzuffi et al. (1994), Gomes et al. (1994), Wilson-Fahmy et al. (1993), among others. This issue was discussed in the keynote lectures of major soil reinforcement conferences (e.g., Bolton, 1991; Jewell, 1993). Although stress-confinement effect is a well recognized fact, its potential significance has not been demonstrated from a design view point. Ling et al. (1995), in a series of finite element parametric studies, showed that variation of geotextile stiffness within an order of magnitude has negligible effect on the deformations of a typically designed wall; its significance is realized when the stiffness varies a few order magnitudes or when subject to a large external load. This technical note supplements previous finite element study by addressing confinement effect of a nonwoven geotextile from a design view point where its allowable strength is combined with a limit equilibrium analysis.

DESIGN METHODOLOGY

The design procedure utilized herein follows that of Leshchinsky (1994) and Leshchinisky et al. (1995), as briefly summarized below. The procedure determines the required geosynthetic strength and length against internal (tieback) and external (compound and direct sliding) failures. The tieback and compound failure analyses are based on a limit equilibrium method utilizing a log-spiral mechanism, which degenerates to a planar surface if it is indeed more critical. The length to resist direct sliding is determined based on a two-part wedge mechanism. Figure 3 shows a typical chart suitable for designing a vertical wall comprised of granular soil, based on the total required geosynthetic strength (Σt_j) and length to resist compound/tieback and direct sliding failures. Note that the required length to resist direct sliding, as shown, is determined using an interaction coefficient (C_{ds}: the ratio of soil-geosynthetic friction angle to soil internal friction angle) of 0.8.

The geosynthetic strength is expressed through a non-

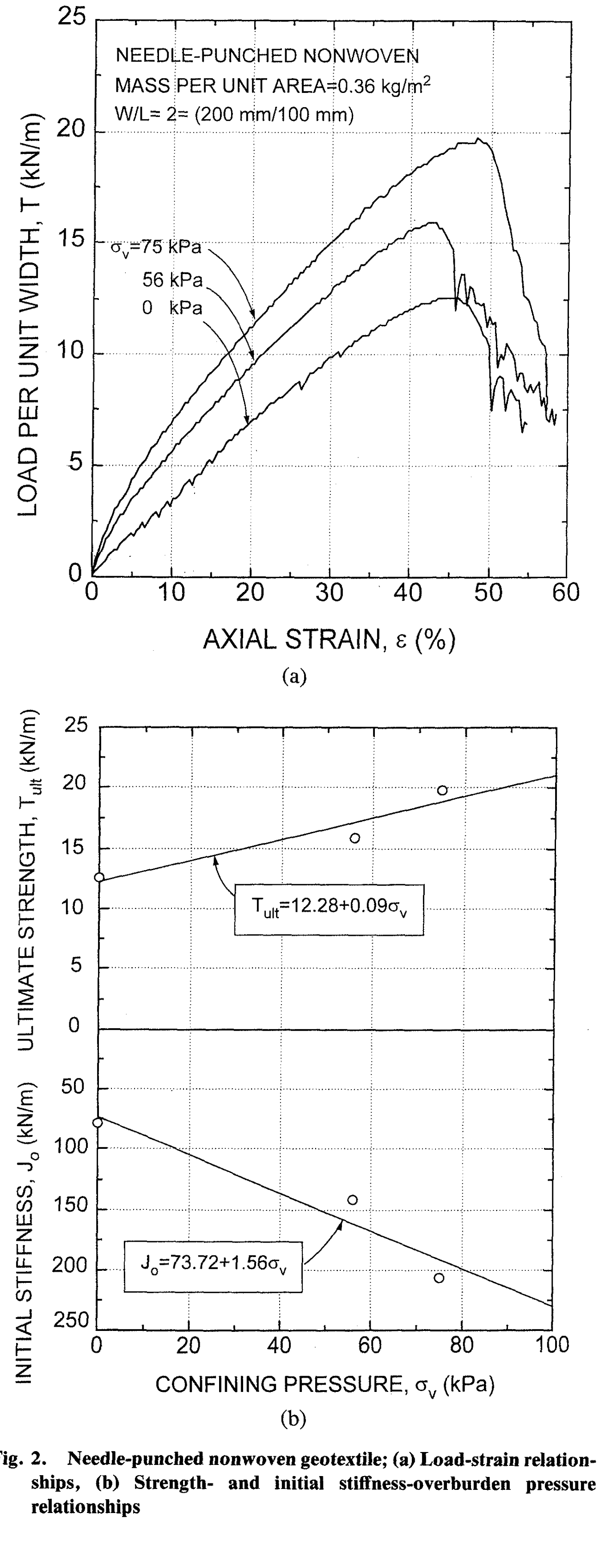


Fig. 2. Needle-punched nonwoven geotextile; (a) Load-strain relationships, (b) Strength- and initial stiffness-overburden pressure relationships

dimensionalized coefficient (K), which is analogous to the earth pressure coefficient:

$$K=\frac{\sum t_j}{\frac{1}{2}\gamma H^2}\approx\frac{t_j}{\gamma h_j D_j} \tag{1}$$

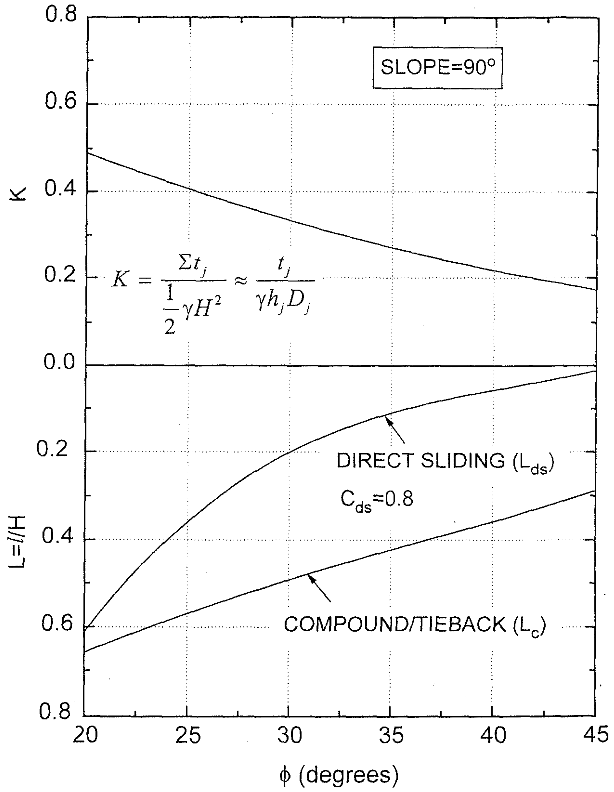


Fig. 3. Design chart for cohesionless soil: Vertical wall

where γ and H are the unit weight of soil and the wall height, respectively; h_j the depth of j-th geosynthetic layer measured from the wall crest, and D_j the tributary area of layer j. The tieback analysis assures local stability at each elevation. To ensure global stability, where failure extends from the wall face and into the retained soil, geosynthetic having allowable strength greater than or equal to that calculated from tieback analysis is specified for each layer in compound analysis. Typically, at layer j, the specified geosynthetic has allowable strength, $t_{j\text{-}allowable}$, larger than the required strength, t_j. It is, thus, practically required that only the bottom m layers to be designed against compound failure so that the following relationship is satisfied:

$$\sum_{j=1}^{m} t_{j\text{-}allowable}\geq\sum_{j=1}^{n} t_j \tag{2}$$

The geosynthetic layout is decided for the top layer based on the maximum length required to resist tieback/compound failure ($l_c=L_c\times H$), and for the bottom based on the length required to resist direct sliding ($l_{ds}=L_{ds}\times H$) or l_c, whichever greater. For a vertical wall comprised of granular soil, it is seen from Fig. 3 that the required length is dictated by that of the tieback/compound failure. Note that this may not be the case if seismic effect and/or small value of C_{ds} are considered (Ling et al., 1997). The length required to resist pullout failure $l_{e,j}$, is determined from the following relationship so that the required geosynthetic force, t_j, will be mobilized:

$$l_{e,j}=\frac{t_j}{2C_i\cdot\sigma_{v,j}\tan\phi} \quad (3)$$

where C_i is the soil-geosynthetic pullout interaction coefficient, ϕ is the soil internal friction angle, and $\sigma_{v,j}$ is the average overburden stress acting on the geosynthetic layer.

COMPARATIVE DESIGN

The comparative design as presented herein is conducted using unconfined and confined strengths of a needle-punched nonwoven geotextile (Fig. 2). The relationships between ultimate strength (T_{ult}) and overburden pressure may be expressed using a linear relationship within the range of stress levels investigated:

$$T_{ult}=T_0+\Delta T\cdot\sigma_{v,j}=T_0+\Delta T\cdot\gamma\cdot h_j \quad (4)$$

where T_0 and ΔT are the unconfined strength and the linear change of strength per unit confining pressure (*see* Fig. 2(b)), respectively.

The allowable design strength of a geosynthetic is obtained by applying partial factors of safety to its ultimate strength (Koerner, 1994):

$$T_{allow}=\frac{T_{ult}}{FS_{ID}\cdot FS_{CR}\cdot FS_{CD}\cdot FS_{BD}} \quad (5)$$

where FS_{ID}, FS_{CR}, FS_{CD}, and FS_{BD} are the partial factors of safety for installation damage, creep, chemical and biological degradations, respectively. These factors are here selected as 1.1, 2.0, 1.0, and 1.0, respectively, following Koerner (1994), which is in equivalent to a lumped

Table 1. Required geotextile strength and anchorage length

layer No j	height (m) h_j	overburden pressure (kPa) $\sigma_{v,j}=\gamma\cdot(H-h_j)$	available strength (kN/m) $t_{d,j}$	strength required to resist tieback failure (kN/m) t_j	strength required to resist compound failure (kN/m) $t_{j\text{-allowable}}$	anchorage length (m) $l_{e,j}$
(a) Wall 1-unconfined geotextile strength (H=3.0 m, D=0.3 m)						
1	0.0	54.0	5.58	5.40	5.58	0.11
2	0.3	48.6	5.58	4.86	5.58	0.12
3	0.6	43.2	5.58	4.32	5.58	0.14
4	0.9	37.8	5.58	3.78	5.58	0.16
5	1.2	32.4	5.58	3.24	5.58	0.19
6	1.5	27.0	5.58	2.70	2.70	0.11
7	1.8	21.6	5.58	2.16	2.16	0.11
8	2.1	16.2	5.58	1.62	1.62	0.11
9	2.4	10.8	5.58	1.08	1.08	0.11
10	2.7	5.4	5.58	0.54	0.54	0.11
(b) Wall 2-confined geotextile strength (H=4.8 m, D=0.3 m)						
1	0.0	86.4	8.94	8.64	8.94	0.11
2	0.3	81.0	8.73	8.10	8.73	0.12
3	0.6	75.6	8.52	7.56	8.52	0.12
4	0.9	70.2	8.31	7.02	8.31	0.13
5	1.2	64.8	8.10	6.48	8.10	0.14
6	1.5	59.4	7.89	5.94	7.89	0.14
7	1.8	54.0	7.68	5.40	7.68	0.15
8	2.1	48.6	7.47	4.86	7.47	0.17
9	2.4	43.2	7.26	4.32	7.26	0.18
10	2.7	37.8	7.05	3.78	3.78	0.11
11	3.0	32.4	6.84	3.24	3.24	0.11
12	3.3	27.0	6.63	2.70	2.70	0.11
13	3.6	21.6	6.42	2.16	2.16	0.11
14	3.9	16.2	6.21	1.62	1.62	0.11
15	4.2	10.8	6.00	1.08	1.08	0.11
16	4.5	5.4	5.79	0.54	0.54	0.11
(c) Wall 3-confined geotextile strength (H=3.0 m, D=0.38 m)						
1	0.0	54.0	7.68	6.75	7.68	0.15
2	0.38	47.3	7.42	5.91	7.42	0.17
3	0.75	40.5	7.16	5.06	7.16	0.19
4	1.13	33.8	6.89	4.22	6.89	0.22
5	1.50	27.0	6.63	3.37	3.37	0.14
6	1.88	20.3	6.37	2.53	2.53	0.14
7	2.25	13.5	6.11	1.69	1.69	0.14
8	2.63	6.8	5.84	0.84	0.84	0.14

factor of safety of 2.2. Thus, the unconfined strength and rate of change of strength correspond to 5.58 kN/m and 0.04 (kN/m)/kPa, respectively. The backfill soil is assumed to have an unit weight $\gamma = 18$ kN/m^3 and internal friction angle for design $\phi = 30°$. C_i is specified as 0.8, which is considered typical value for geosynthetic pullout failure (e.g. Milligan and Palmeira, 1987).

First, the design seeks the maximum height of a vertical wall based on the unconfined and confined geotextile strengths, designated as Wall 1 and Wall 2, respectively. For simplicity, a uniform geotextile spacing $D = 0.3$ m is considered. Details of the design, including the required geotextile strength and anchorage length at each layer, are given in Table 1(a) and (b), respectively. The unconfined geotextile strength allows a 3.0 m high wall whereas the confined strength gives a higher wall: 4.8 m. As can be read from Fig. 3, the required length to resist tieback/compound failure is 1.5 m and 2.3 m for the first and second walls, respectively. Their greatest anchorage length, l_e, is at layer 5 ($l_e = 0.2$ m) and layer 9 ($l_e = 0.2$ m), which gives a total length of 1.7 m and 2.5 m, respectively. The layout of these two walls are shown in Fig. 4. It has to be noted that for the higher wall (Wall 2), a larger total geotextile length is needed. The total amount of geotextile used in Wall 2 may, however, be reduced if a nonuniform spacing is specified in design.

Next, a design is conducted for the third wall (Wall 3), of height similar to Wall 1, i.e., 3 m, but utilizing the confined strength of geotextile. The design allows 8 geotextile layers at an equal vertical spacing of 0.38 m. This spacing resulted in about 20% less total geotextile length per unit width of the wall. As given in Table 1(c), the total length of each layer is calculated as 1.7 m.

Although the design comparison as presented herein was based on vertical walls, reinforced soil retaining walls of other inclinations, including seismic effect, may be conducted using confined strength with reference to the charts presented in Ling et al. (1997). In addition to tensile reinforcement, nonwoven geotextiles offer additional benefits of facilitating drainage and dissipation of excess pore water pressure if low quality cohesive backfill soils are used (e.g., Tatsuoka and Yamauchi, 1986; Ling and Tatsuoka, 1994). Based on the results of this comparative study, it is recommended to standardize the confinement test of geotextile so that potential benefits of this reinforcement material may be realized in practice and design.

SUMMARY AND CONCLUSIONS

Stress-confinement improves the tensile properties of needle-punched nonwoven geotextiles. Based on a rational design procedure, the unconfined and confined strengths of a typical needle-punched nonwoven geotextile are used to conduct a comparative design of vertical walls. It is shown that in a typical granular backfill, the confined geotextile strength allows a taller wall to be conducted. Conversely, for in a selected wall height, less geotextile layers are needed based on the confined strength having the same factor of safety. The effect of confinement may be equally demonstrated with other design procedures. Nonwoven geotextiles offer benefits for certain projects due to its low cost and drainage capability when used with low-quality backfill soil. Apparently, potential benefits of its confined strength may also be considered in design. Thus, a simple stress-confinement test,

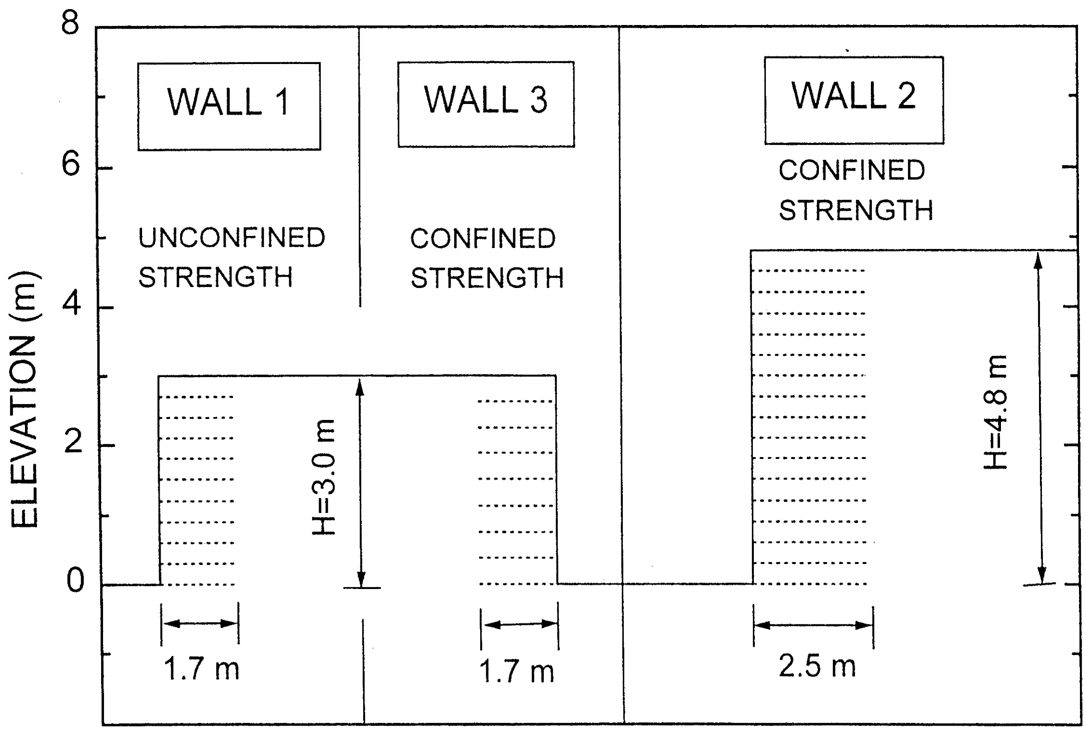


Fig. 4. Layout for comparative wall designs

which has to be easy to conduct and to interpret, is recommended as standard.

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