Repair of a Reinforced Earth Wall

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SYNOPSIS The facing of a Reinforced Earth retaining wall, built at an altitude of 1200 m, was damaged during the winter 1981. The repair was achieved quickly and under traffic. The instrumentation carried out on the repairs and the tests run on the backfill material have revealed the action of the frost and its increase in the fortuitous presence of water.

I - DESCRIPTION OF THE ACCIDENT

On Wednesday 11 March 1981, around 7 p.m., the breakage of about 60 m2 of facing of a Reinforced Earth wall was reported on the access road of Frejus Tunnel (1200 m in altitude). This road is 5 km long comprising over 10 000 m2 of Reinforced Earth walls. The structure in question was built in 1978. No hint of breakage had been reported.

The following observations were made on the site :

1) The rupture concerned a surface of facing 9 to 10.5 m wide and 6 m high near the top of the wall and resulted from the breakage of the strips at the connection. There was no trace of corrosion on these strips (fig. 1).

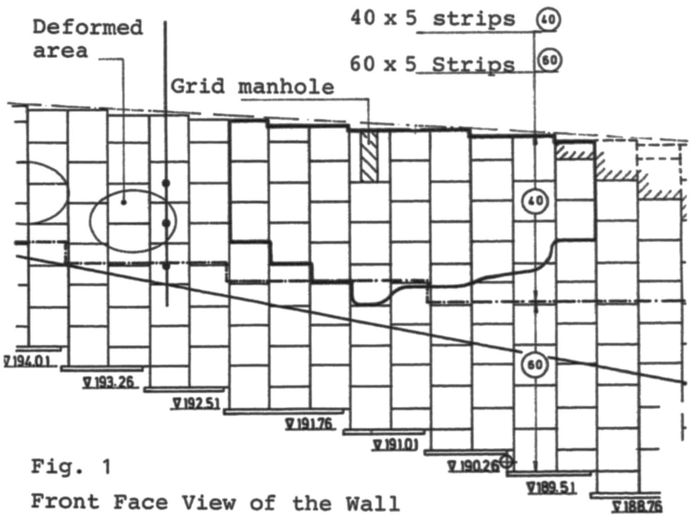


Fig. 1

Front Face View of the Wall

2) The part of the facing that collapsed contained 40x5 strips. Right below, the 60x5 strips were not broken.

3) A portion of backfill (1 or 2 m thick), which can be considered as the "active zone" of the Reinforced Earth mass, failed with the facing. According to witnesses, this backfill was saturated.

4) Behind the collapsed area, the reinforced structure remained perfectly coherent.

5) In the centre and at the top of the collapsed area was a grid manhole about 2 m deep, conducting the running water towards the main sewer of the uphill bank of the road through a Ø 300 mm transverse pipe. Although the manhole was displaced and broken, it could still be observed that no re-bar had been placed to tie its walls to the bottom slab.

6) Beside the collapsed area, bulges could be observed in several areas of the facing.

II - REPAIR OF THE WALL

The repair was carried out in two phases :

a) In the collapsed area the facing was rebuilt through pouring a grid-reinforced concrete panel and connecting it to the reinforcing strips left in the backfill (fig. 2)

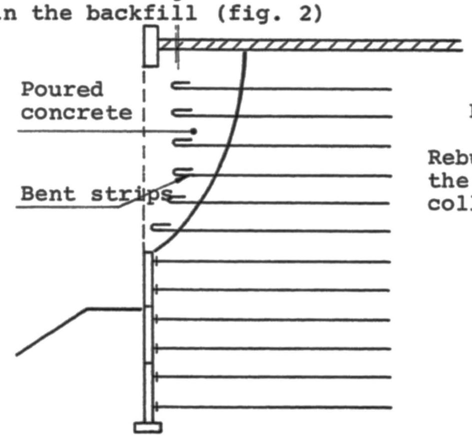


Fig.2

Rebuilding of the facing of collapsed area

b) Nailing of the facing in the deformed areas using passive rods (Dewidag rods) injected in a prebored hole. We used Ø 28, 42000 MPa bars, threaded towards the panel side and passing through the panels at their center (fig.3).

Fig. 3

Nailing facing

Between the anchorage points and the panel we placed 200x200x10 mm steel distribution plates. The tightening was achieved wih a 20kN dynamometric spanner. The injection grout that was used was composed of a siliceous sand with grains not exceeding 2 mm and P350 Portland cement.
Mortar composition :
- Cement 650 kg
- Sand 600 l
- Water 375 l

No expansive additive was used.

The injection was carried out in two phases :

a) One meter long embedding of the bar at the bottom of the hole without pressure, using a plunging stick.

b) The following day, injection under pressure through a steel plate provided with a connection to the injection flexible hose and a spiracle.

The injection was completed without pressure to fill the borehole. After closing the spiracle we brought the pressure up (from 2 to 5 bars), in function of the resurgences occurring generally through the panel joints). The average quantity injected was three times superior to the theoretical volume of the boring. In both areas thus repaired, only the facing was rebuilt or consolidated, the Reinforced Earth mass having suffered no damage.

III - INSTRUMENTATION OF THE STRUCTURE (fig.

It was decided to take the opportunity of thi repair to carry out an instrumentation of the structure in order to understand its behavio under the effect of frost, which apparently w the cause of the incident.

The instrumentation was carried out following transverse profile of the wall situated 2.25 uphill of the collapsed part in the consolida area.

Three parameters were measured :

- Temperatures : 15 gauges were placed at the back of the facing and 1 at the top of the st ture in order to measure the external tempera ture(fig. 4)

- Tensile stresses : 3 rods were provided wit "GLOETZL" direct reading gauges.

- Rotations : an insert was sealed to each pa of the profile in order to carry out rotation measurements with a precision levelling instr ment (L.C.P.C. type).

* Temperature gauges
Levelling instruments
"GROETZL" gauges

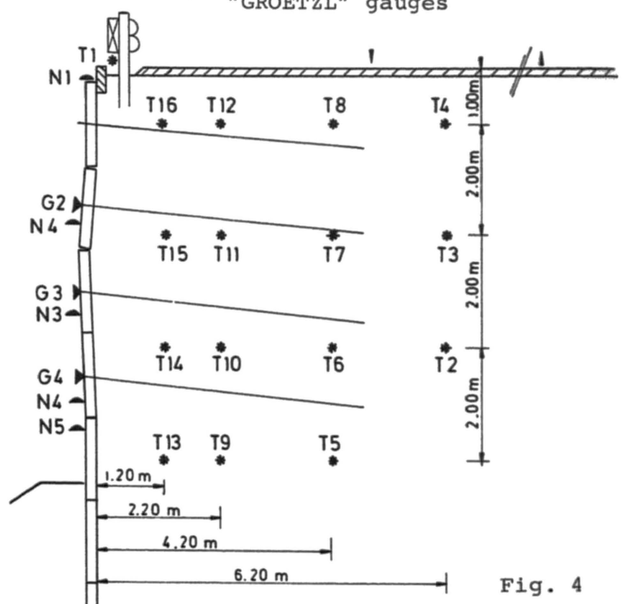


Fig. 4

Instrumentation of the consolidated

IV - MEASUREMENT RESULTS

The recording of temperatures started on 18 November 1982, and the rotation and tensile stress measurement on 22 November.

1) Temperatures

Daily temperature average was recorded insid the structure (1 every two hours).

. The outside lowest temperatures were reach on 12 February (-17,6°C).

. The lowest temperatures inside the structu were recorded at the beginning of March (fig.5) i.e, three weeks later.

. The frost deeply penetrated the top part c the structure (4.20m behind the facing). part of the structure is in fact submittec the frost coming from the road and the Reinforced Earth facing.

. On a lower part the frost penetrated as far as 1.5 m behind the facing.

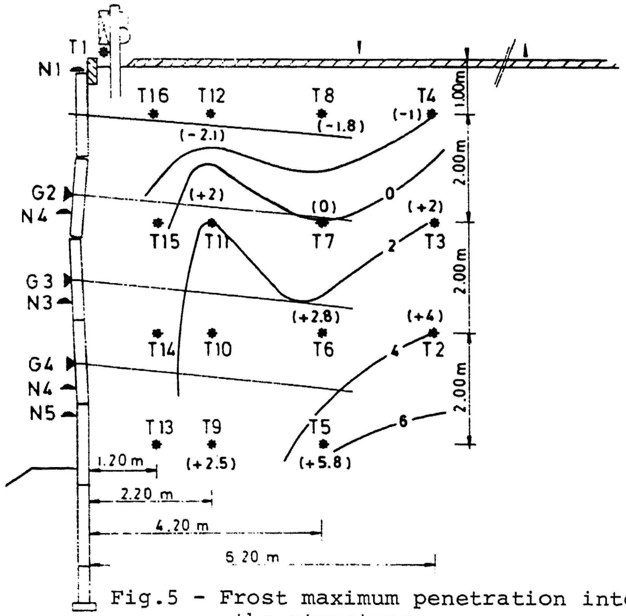


Fig.5 - Frost maximum penetration into the structure

2) Tensile stress in the rods (fig.6)

The maximum tensile stress observed in the rods was noted on 23 February when the outside temperature had risen (maximum 5,7°C, minimum - 8,7°C) and when the frost went on penetrating

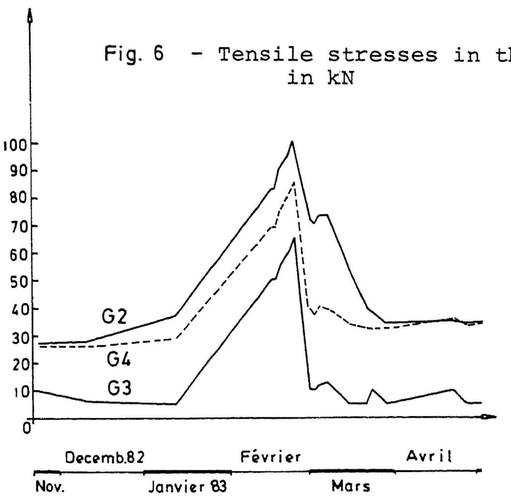


Fig. 6 - Tensile stresses in the rods in kN

An increase in tensile stress was noted : 70 kN on G2 and 60 kN on G3 and G4.
This increase in tensile stress applied to the four strips of a panel gives an increase of 15 kN per strip. Normally, the maximum working stress of the strip is 180 MPa, namely a force of $180 \times 5 \times 40 \times 10^{-3} = 36$ kN
Near a hole this stress is reduced by 25% i.e. a maximum stress of 27 kN.
When the test took place each strip could have then been submitted to a force of 27+15=42 kN i.e. a force inferior to the shearing stress of the tie-strip (51,5 kN). In this case the stress in the steel at the connection is :

$42/[(40-13) \times 5 \times 10^{-3}] = 311$ MPa i.e. a stress superior to the elastic limit of 240 MPa.

3) Rotations

At the time when the tension was maximum in the rods, very slight rotations of the panels were reported in the order of 5×10^{-4} to 20×10^{-4} rad.

It was observed that water was running through the facing near the instrumented profile in spite of the precautions taken concerning the running water which is collected at the surface and drained outside the structure. It is likely that this water came from the back of the structure, the draining curtain placed at the back of the Reinforced Earth mass not being efficient.

We shall see in the interpretation of the frost phenomenon that the presence of this water plays an undoubtedly important part.

V - ANALYSIS OF THE FAILURE OF THE REINFORCED EARTH STRUCTURE

It is naturally assumed that the frost probably caused the incident all the more so since winter in that region had been very hard and long (frost grade : 296,8°C x d .). Two assumptions were made:

a) The failure had occurred under the water-earth mixture pressure at the thawing time.

b) The rupture of the connections occurred while the backfill was submitted to frost. The facing collapsed at the time of thawing.

Hypothesis a) was rejected because the maximum pressure that could be obtained with this completeley saturated soil would be insufficient to break the connections :

$P = h \times (Ka\gamma' + \gamma w)$
(where P = pressure of the mixture water+soil)

Ka = coefficient of earth pressure
h = max. height
γw = unit weight of water
γ' = unit weight of soil

For h = 6m, Ka = 0.33 γ' = 13 kN/m3 γw=10kN/m2
P = 86 kPa which leads to a stress of :

$86/4$ strips : $[(40-13) \times 5 \times 10^{-3}] = 159$ Mpa

which is less than the admissible value for steel (180 Mpa).

Water + backfill pressure is then theoretically insufficient to explain the breaking of the strips at the tie-strips at a 6 m depth. The calculation applied to the top part of the structure would show a much larger margin for safety. We know, from prior observations on other structures that the unlikely failure of a facing panel at 6 m depth would not cause the collapsing of the panels located above.

Our second hypothesis (failure due to frost causing the backfill behind the facing to swell) was based on our knowledge of the swelling of soils and on the complementary tests carried out in the regional laboratory of Nancy.

VI - GENERAL BEHAVIOUR OF THE SOILS UNDER THE INFLUENCE OF FROST (2)

Generally speaking, the soils can be classified in 2 main categories according to their behaviour at freezing point :

- The non expansive soils where freezing does not affect the structure of the soil and its water content. It is the case in particular of granular soils. Yet a slight swelling can be observed, due to the increase in water volume through freezing. The extent of the swelling depends on the degree of the soil saturation.

- The expansive soils on the contrary present a change of their structure, an increase in their water content and a noticeable swelling. In general, those soils contain a large part of fine particles. Besides silts, clay and marl we also find degraded lime-stone or sand-stone.

It must be noted that the expanding capacity of a soil will occur all the less as its drainage is efficient, disregarding any other characteristics. Frost specialists even think that a very expanding soil placed under conditions such as to have an initially low water content and to make it impossible for water to flow (for example thanks to a waterproof envelope) will behave practically like a non expanding soil.

Classification of the Expanding Soils

As a reminder we will recall CASSAGRANDE and the US CORPS OF ENGINEERS Classifications which are not presently used in France.

In France, the soils are classified according to a frost susceptibility test run in laboratory on soil samples recompacted to Normal Proctor

During the standard test, the top of the sample is maintained at a temperature of -5.7°C. its toe is plunged in a water tank with a constant level maintained at a temperature of +1°C.

The following paremeters are recorded during the test : temperature, expansion and time. They allow to establish the relation $G = f(\sqrt{I})$ and to calculate the slope of this straight line

G = expansion in mm
I = frost coefficient in Cxh
= temperature in °C x number of hours

The soils are classified in three classes of sensitivity to frost corresponding to the slope limits of the straight lines $G = f\sqrt{I}$ as follows

Slope in mm/$\sqrt{C° xh}$	0.5	0.4	
Class of sensitivity to frost	SGn unexpand.	SGp little expand.	SGt very expand.

Expansion test on the Frejus wall backfill

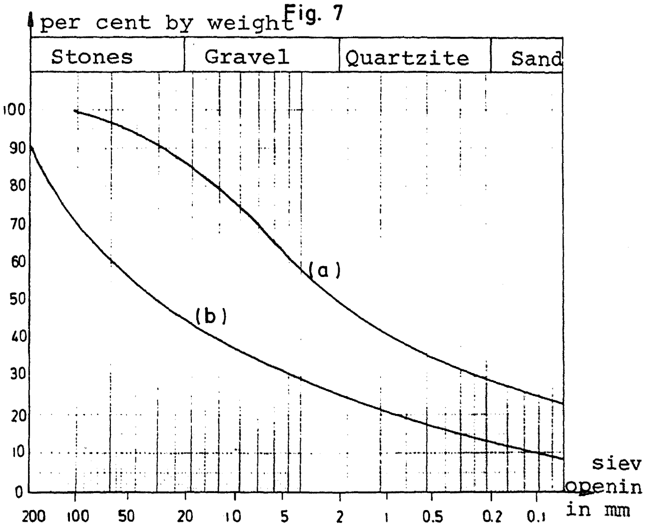
The backfill materials used in this structure belong to 2 categories :

- Fill coming from the excavation of the access gate or from the wall pit itself (fig.7a). The percentage of fine backfill is over 15 %.

- The quartzite materials of an existing quarry (fig. 7b).

We chose to test portions 0/20 and 0/5 mm of soil a) which seemed the most expanding one.

Fig. 7



We completed this frost susceptibility test by carrying out the same test with a sample not supplied with water. The last test was designe to allow us to check a possible self-expansion of the soil during the freezing phase.

The materials criteria (water content, depth o the frost front) are shown on table of fig.8. The results on expansion are shown on the tabl of fig. 9

The differences of behaviour of the 2 samples material 0/5 and 0/20 is not significant, the differences of slope are small and about the same amplitude as the diffusion phenomenon cu rently observed in this type of test.

The expansion in the samples with no water is 5 to 10 times inferior to that observed in th samples supplied with water. This actually co firms the pre-eminent part of the water in th size of the expansion.

The coefficient of frost at the time of the t being I = 5.7°C x 230 h = 1,311

We obtain the following expansions :

G = 7 to 8 for the soil supplied with water
G = 0.7 to 1.8 mm for the soil not supplied with water
at a frozen depth of about 200 mm.

The extrapolation of the results of the labor tory tests to the Frejus wall case is very ri Indeed a great number of the test conditions absent on the site :

- Spreading of the frost front is unidirectio in the test and bidirectional in the wall. Th frost front penetrates as far as 4 m in the t part of the structure and 2 m in the lower pa (see fig.5).

- The laboratory test is run in enclosed envi ment in 2 directions ; on the site, the expan is possible at least in 2 directions.

Test conditions	Gradation	Water content in %			Frost front depth
		Before test	After test	Frost front	
Water supplied	0/5 mm	13.8 13.8	19.5 19	27.6 26	200 mm 190 mm
	0/20 mm	11.5	15.8	17.5	130 mm
No water supplied	0/5 mm	14 14 14 13.9	14.2 14.5 14.3 14	12.4 14.4 14.7 12.6	180 mm 190 mm 190 mm 190 mm
	0/20 mm	11.2	11.2	13.7	150 mm

Fig;8 - Materials characteristics

Test conditions	Gradation	Slope Δ x G/$\Delta\sqrt{I}$	Frost susceptibility
Water supplied	0/5 mm	0.19 0.19	SGp
	0/20 mm	0.23	SGp
No water supplied	0/5 mm	0.02 0.04 0.05 0.05 0.05	Behaviour equalent to a SGn soil
	0/20 mm	0.04	

Fig. 9 - Swelling test results

CONCLUSION

The failure of the facing of a Reinforced Earth structure which occurs in 1981 on the access road of the Frejus tunnel was-caused by the expansion of the backfill under frost action near the facing, this backfill being supplied with water running from a defective grid manhole.

The repair conducted under traffic by replacing the facing in situ and nailing the deformed parts pointed out the good behaviour of the structure in the absence of the facing.

The frost susceptibility test run in laboratory and the monitaring of tensile forces carried out on the nails of the consolidated area made obvious the pre-eminent part payed by water in the extent of the expansion, therefore of the efforts applied directly to the facing.

The extrapolation of the test results in laboratory to a real structure is risky . There remains for us to instrument an experimental structure with a controlled supply of water ; we would measure on materials of various sensitivity to frost the evolution of the strain along the strips, especially at the connection in fonction of the development of the frost front and the coefficient of the surface frost. Without waiting for the results of such an experiment it is already decided to intensify the protection against the water infiltrations in Reinforced Earth structures to be built in areas where the coefficient of winter frost expressed in C x day reaches 250°C x d. The decisions taken will be entered in the Recommandations and Rules of the Art (3). It is interesting to note that among hundred of Reinforced Earth structures built in the last 15 years worldwide in very cold regions, only the Frejus structures was damaged.

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