Some Observations on Deconsolidation of Limey Rocks on Steep Slopes

Quelques Observations sur la déconsolidation de roches calcaires sur pentes fortes

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SUMMARY

A number of cases are described in which deconsolidation of chalky and limey rocks appears on slopes over 25°. This phenomenon often results in the formation of gliding planes parallel to the ground surface. As a rule, the deconsolidated zone lies below a calcareous crust (characteristic of semi-arid conditions) 2 to 3 m thick. This deconsolidation may develop into rock creep or rock slides. Its detection is most important in evaluating high building foundations. Similar observations were also made on slopes consisting of dolomite.

SOMMAIRE

On décrit un certain nombre de cas de déconsolidation de roches calcaires et crayeuses sur des pentes de plus de 25°. Ce phénomène aboutit souvent à la formation de plans de glissement parallèles à la surface du sol. En général, la zone déconsolidée se trouve sous une carapace calcaire (caractéristique des conditions semi-arides) d'une épaisseur de 2 à 3 mètres. Cette déconsolidation peut se transformer en fluage ou en glissement. Il est important de reconnaître ces phénomènes lors de l'étude de fondations de hautes constructions. Des observations semblables ont été faites sur des pentes de dolomite.

THE PRACTICAL IMPORTANCE of the disintegration of steep rocky slopes has been stressed for some time by a number of authors (Lugeon, 1933; Gignoux, 1955; Bollo, 1961; Terzaghi, 1962; Klieslinger, 1958; Mueller, 1962; etc.). The phenomenon is generally explained by the "poussée au vide", the decompression or stress-relief of the rock in a relatively young slope. In the course of investigations for high-building foundations on steep slopes, numerous instances of this process have been observed in the semi-arid conditions found in northern Israel. A few of these instances seen in the Carmel Area, Haifa, are described.

CASE DESCRIPTION

Example 1 (Carmel, eastern slope)

Nine- to eleven-storey buildings had been contemplated on a steep slope, 50 m high, varying 20° to 30°. The main rock is a hard massive chalk, interbedded with some crystalline limestone and marly chalk. The dips are flat. The ground surface is covered by 1.5 m of hard "nari" crust at the top, and 2 m of soft nari below. Nari is a characteristic formation for calcareous regions in semi-arid conditions. Its formation is caused by the deposition of carbonate from ascending solutions in the dry season. The groundwater table is deep.

Test pits excavated for investigating the foundations have shown below the nari a zone, 2.5 to 4 m thick, with numerous fractures, some of them very wide (up to 10 cm) which dislocate the rock structure. Some amorphous calcite covered the walls of these fractures. This zone was found to be more or less parallel to the slope. On the opposite slope of the small young "wadi" (dry torrential river bed) which borders the site, two small slide scars were observed, pointing to the instability of the slope.

Additional drillings confirmed the existence, underneath the nari, of a disintegrated zone which at some places may be very thick and seemed to be greater near the bottom of the slope than near the top. During the excavation of the foundations, numerous zigzag fractures, following the joints and bedding, could be seen which were wide open in the vertical parts and closed in the horizontal parts, thus showing a certain amount of movement to have taken place towards the valley.

A comprehensive analysis of these observations leads to the hypothesis that at some time during a more humid period, the slope had started to deconsolidate and some local surface movement had taken place; in the present relatively dry period, nari was formed on the slope and increased its stability to some extent.

Example 2 (Carmel, northern slope)

Eight-storey housing developments are to be built on a long, 30° slope, 150 m high and consisting of limestone, chalky and flinty, gently dipping into the mountain. The rock is "narified" at its upper surface; groundwater is deep.

The ground structure, clearly indicated by a road trench and a number of ancient, collapsed underground quarries, is as follows: 1 m of narified limestone; 2–3 m of limestone with open fractures, showing some signs of movement. The fractures are vertical, horizontal, and oblique and delimit large blocks of over 1 cu.m. Below: sound rock with a few closed joints.

Seismic measurements and three correlation diamond drill holes have shown that the sound rock surface runs roughly parallel to the ground surface, at a depth reaching 10 m.

Example 3 (Carmel, western slope)

High buildings are being erected near a narrow and deep young wadi, where slopes reach 40° and are up to 30 m high (Fig. 1). The rock is a massive chalk, somewhat marly or limey, and contains thin flint beds. The dips are flat. Groundwater is deep. The upper part is narified and the rock is generally fractured to a depth of 2 to 3 m, but near the wadi cliffs, sometimes up to 6 m or more. The width of

FIG. 1. Housing project on young wadi slopes.

FIG. 2. Deconsolidation fissure cutting chalky cliff.

FIG. 3. Gliding deconsolidation fissure in flinty chalk.

these fractures reaches 20 cm in some cases. Near the surface they are filled with clay. Lower down, their walls are coated with calcite. Here again small caves frequently develop in the fractured zone.

In the wadi cliff one can clearly see the fractured zone, separated from the sound rock by fissures running parallel to the ground surface and cutting across the bedding (Fig. 2). These fissures, which are sometimes well polished so as to give a false impression of fault planes (Fig. 3), demonstrate that the deconsolidated zone has moved somewhat above the lower sound rock. Some of the fissures have been observed to cut an angle of 40° with the horizontal plane, with an extension of 10 $\times$ 10 sq.m.

In the foundation pits, wide fissures are visible (Figs. 4

FIG. 4. Wide-open deconsolidation fissure in chalk, 2 m deep in test pit.

FIG. 5. Fractured, deconsolidated chalky rock in test pit, at a depth of 1.5–2 m.

FIG. 6. Deconsolidation fissure cutting bedding in flinty chalk, at a depth of 2 m in test pit.

and 5) parallel to the 20° slopes, below the nari, sometimes running across the bedding in an irregular way and giving the impression that the upper zone is being detached from the lower (Fig. 6).

Numerous fissures, similar to those described, can be seen in sufficiently deep excavations in the steep slopes on which the town of Haifa is built, particularly fissures running parallel to the slope (Fig. 7).

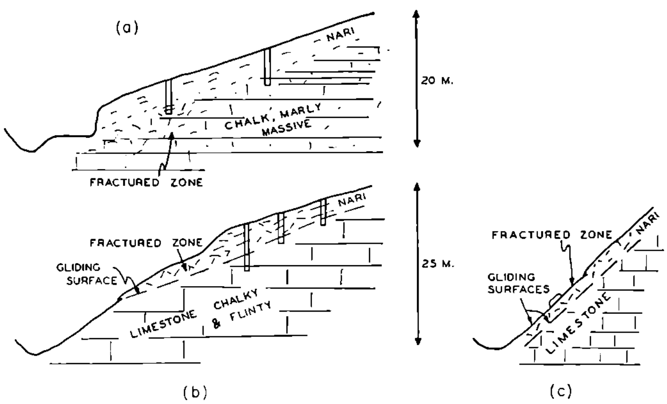

FIG. 7. (a) Fractured zone in chalk, below nari; (b) gliding plane below fractured limestone zone; (c) gliding planes in fractured limestone zone.

Example 4 (slope in dolomite rock, Carmel)

The dolomite slopes are inclined at about 25°. Although nari does not develop in this rock, the surface is somewhat weathered. The deconsolidation zone is easily observed in numerous quarries; the rock is much fractured and disintegrated. The thickness of the deconsolidation zone rarely exceeds 2 m. Here again, one or more wide fissures, running parallel to the slope, separate this zone from the sound rock. The phenomena described are found repeatedly in other parts of the country.

It should be pointed out that talus breccia, more or less cemented by clay or calcite, is found on steep 30° slopes in the Carmel area and is covered by thick nari. It does not, however, show signs of deconsolidation or fissuration as in the cases described above.

TENTATIVE EXPLANATION

The process of deconsolidation of a young slope made of hard rock can be easily understood, assuming that stresses near the slopes increase immediately after erosion has taken place, as may be seen near the walls of a recently excavated tunnel. These increased stresses may break the rock after some time, and even put it in a plastic state, while gravity tends to dislocate it either by ravelling or by mass movement, or both, according to the degree of cohesion and internal friction. In ravelling, individual blocks tend to detach from the mass one after the other. Mass movement may occur without any distinct surface between the moving and the resting rock (Examples 1 and 2) or in a shear surface, more or less parallel to the slope (Examples 3 and 4). This mass movement may develop into a creep or a superficial slide. Weathering, surface, and internal erosion tend to accelerate the movement, while climatic change towards semi-arid conditions results in the formation of crusts which may decrease the velocity of the moving zone and somewhat stabilize the slope.

A number of factors still have to be thoroughly studied, the influence of the slope angle, the strength characteristics of the rock, and especially the history of the development of the slope.

PRACTICAL CONCLUSIONS

Since high buildings cannot be based on nari, which is irregular and unreliable, foundations will have to rest either on the doubtful deconsolidated zone or on the sound rock below. The first solution may be unsafe, especially in areas of heavy rain or earthquake. The second solution, however costly, is safer, provided means are taken to separate the structure from the upper unstable zone. This solution was worked out by the designer's consultants for the buildings mentioned in Examples 1 and 3. These buildings stand satisfactorily at present.

If the building must be based on the deconsolidated zone because of the great depth of the sound rock, special care should be taken to disturb the rock as little as possible and to provide proper drainage.

SITE INVESTIGATION METHODS

In order to know in advance the geological conditions at the building site, three methods may be practically applied: (*a*) test pits which give valuable information if dug deep enough, but which are expensive; (*b*) diamond drill holes which give good information as long as full core recovery is ensured, which is not always possible in the upper strata. Nor is it always easy to distinguish between deconsolidated and sound rock since drilling may open the fissures of the latter; (*c*) seismic surveys by portable instruments (hammer type) yield excellent results in most cases. Nari, deconsolidated and sound rock can be easily separated (order of magnitude of velocity in nari: 300 to 600 m/sec, in deconsolidated rock up to 1000 m/sec, in limestone 2000–3000 m/sec). This method has the added advantage of being inexpensive.

Where the above-described phenomena are expected, it is recommended to start site investigation by a seismic survey and to check or complete results by a number of drill holes or test pits. It is evident that any pertinent geological information must be collected before the beginning of the investigation.

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