trending diapiric ridges, on which collapse structures are developed. These ridges occur on a line connecting to the Qishon graben, with an active fault north of the area. Though it is difficult to identify reflector N under these structures, it is likely that they mark the submarine extension of the Carmel fault. Its activity induced especially strong flowage in the evaporitic series above the fault and in nearby areas.

References

Almagor, G., 1980. Halokinetic deep-seated slumping on the Mediterranean slope of northern Sinai and southern Israel. *Mar. Geotech.*, vol. 4, pp. 83-105.

Almagor, G. and Garfunkel, Z., 1979. Submarine slumping in the continental margin of Israel and northern Sinai. *Am. Assoc. Pet. Geol., Bull.*, vol. 63, pp. 324-340.

Garfunkel, Z., Arad, A. and Almagor, G., 1979. The Palmahim disturbance and its regional setting. *Isr. Geol. Surv., Bull.* 72, 56 p.

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STABILITY OF CONTINENTAL SHELF SLOPES UNDER EARTHQUAKE LOADING CONDITIONS

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The purpose of this summary is to outline the approach in applying geotechnical methodology, the evaluation of the cyclic load, properties of the continental shelf sediments, and how the results of the geotechnical tests may be applied in order to determine the effects of earthquakes on the stability of the slopes involved. This research was initiated several months ago and is scheduled to be completed in two years.

Mass creep and small rotational slumping are widespread along the entire shelf edge at 80 to 150 m water depth (about 4 km wide strip, 0.5-1° inclination), and the uppermost continental slope, at water depths of 200-325 m (4-5 km wide shore-parallel strip, 1-2.5° inclination) (Neev *et al*, 1976; Almagor, 1976). These strips are characterized by undulating topography, made up of a system of low amplitude, elongated hillocks that are separated by elongated depressions, and by numerous shallow horizontal clefts. This topography is in outstanding contrast to the very smooth, rounded topography of the shelf and upper slope of Israel. The height of these hillocks range between 5 and 15 m, and their width, between 100 and 300 m (rarely 400 m). The clefts are 150-200 m wide and reach 20-25 m depth. The horizontal dimensions of both the hillocks and clefts are less than 1 km long.

Analysis of the static force equilibrium that exists within the shelfedge and upper slope sediments indicates that the sediments are sufficiently strong to sustain the slopes at the shelf edges and upper slope, even if subjected to the effects of earthquake accelerations greater than those detrimental to the steepest slopes (α= 5-7°) of the middle continental slope. However, this analysis indicated that only a minor addition of an earthquake-induced horizontal acceleration of gravity is needed to initiate undrained mass movement of the shelf edge and upper slope sediments , if a static analysis is applied. This means that even a small amount of weakening of the sediments by the low magnitude earthquakes that generally occur in the region, is sufficient to cause mass creep (the term creep, is herein defined as continuous yielding of the soil particles under applied undrained stress).

It is suggested that these creep phenomena reflect long-term deterioration in shear strength of the sediments due to repeated loading effects. Frequent loading reversals can occur rapidly during earthquakes, or more slowly when caused by wave loading. The effects of repeated loading depend mainly on the cyclic stress level, their number, frequency and duration, and on the sediment types. Application of cyclic loading on normally consolidated and slightly over-consolidated clays, where drainage is poor (and on metastable and confined loose sands) will lead to a build-up of pore-water pressure, increased strain and subsequent decrease of shear strength of the sediment with time (Fig. 1). In addition to this long-term deterioration in shear strength which may develop over a period of hundreds and thousands of years, each individual earthquake may cause a further, momentary decrease in shear strength due to a bulid-up of fluid pressure in the sediment pores during action of the quake. If the excess pore-water pressure reduces the effective normal stress to a suf-

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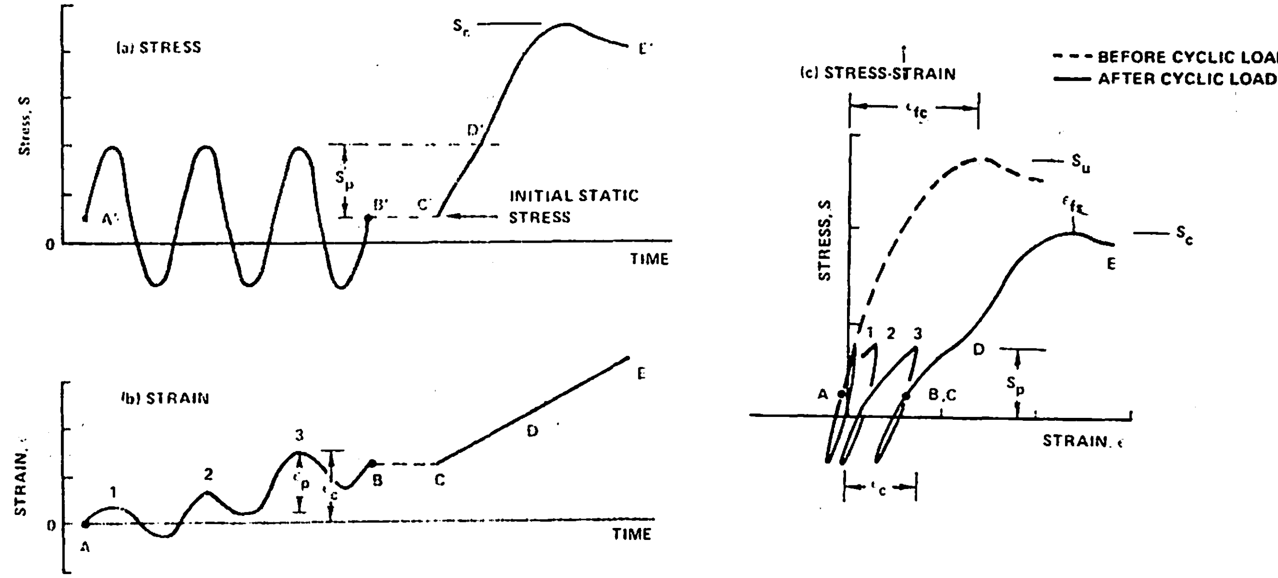

Fig. 1. Illustrative cyclic-static test record. AB and A'B' equal the cyclic stress-strain path; BC and B'C' equal the rest and adjustment period following cyclic loading; CDE and C'D'E' equal the one-directional static loading test; and the dashed curve refers to one directional static loading test on an identical sample with no previous cyclic loading (after Lee and Focht, 1976b).

ficiently low level, an effective stress failure (liquefaction) will develop, which may result in mass movement downslope.

In view of the greater water depth of the sediments involved (above 80 m) and the mild oceanographic conditions in the region, the weakening of the sediments in question (outwardly expressed as creep failures) is probably caused by cumulative effects of earthquakes which are frequent.

As with metal fatigue, it is assumed that the deterioration in shear strength of the sediments is not time history dependant. Thiers and Seed (1969) showed that the deterioration in stress-strain properties is due entirely to the amount of cyclic strain, whether developed by a few strong or many small stress pulses. Therefore, as the sediments of the continental shelf and upper slope represent a complete undisturbed Holocene sequence (Neev *et al*, 1976), cyclic shear testing of long core samples could yield results pertaining to the complete earthquake history of this sedimentary column since deposition, if the basic postulate of the phenomena being independant of time history is correct.

The methodology applicable was formulated by Anderson (1976) and Lee and Focht (1975, 1976a, 1976b), though for ocean waves rather than for earthquake effects. The amount of cyclic softening, as expressed by the decrease of the static stress required to cause failure, is accentuated by increasing prior cyclic loading (Fig. 1). From cyclic tests, such as illustrated in

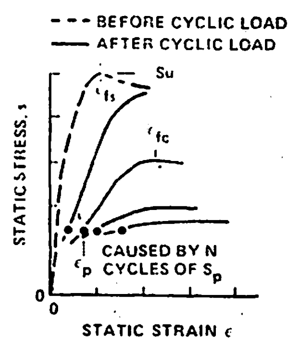

Fig. 2. Illustration of static strength after cyclic loading (after Lee and Focht, 1976b).

Figure 2, series of cyclic strain, strength, and pore-water pressure curves, that are characteristic of the sediment in question, can be developed (Figs. 1 and 3); the failure criterion being the amount of pulsating strain amplitude corresponding to a particular curve. As the effect of pulsating stress cycles in a group of any intensity is assumed to be independant of when it is applied within this group, it is possible to use various assumed earthquake inputs to calculate the cyclic loading effects with time (or number of cycles) on the sediments (Fig. 3). From historical records, which in the

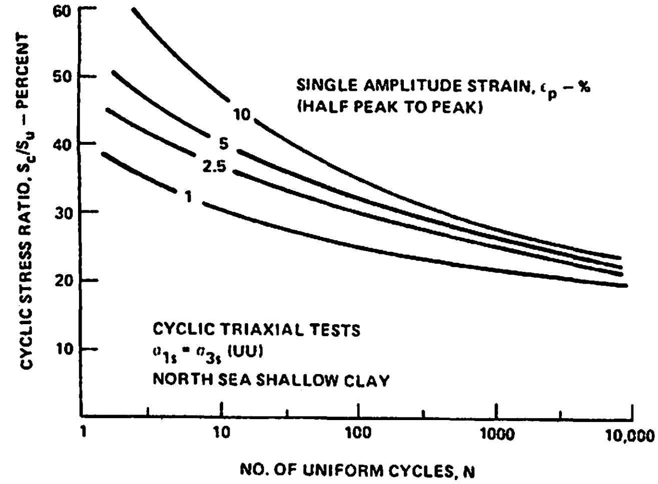

Fig. 3. Effect of cyclic storm loading on clay soil (after Lee and Focht, 1976b).

LEGEND (Figs. 1-3).

S_u - Static strength in an undrained test performed on an undisturbed sample prior to any cyclic loading.

S_c - Static strength in an undrained test following cyclic loading.

S_p - Cyclic strength amplitude.

ε_{fs} - Strain to failure in an undrained test performed on an undisturbed sample prior to any cyclic loading.

ε_{fc} - Strain to failure in a static test following cyclic loading.

ε_p - Cyclic strain amplitude.

ε_c - Accumulative strain.

Middle East contain earthquake data back to some 2,000 years (Willis, 1928; Amiran-Kallner, 1950), a fair approximation of the cumulative earthquake cyclic loading effect can be constructed, and roughly extrapolated to the entire Holocene period. Conversion methods of the randomly irregular earthquake loads, as recorded by use of accelerometers, to equivalent uniform cycles that can be used in the analysis are described by Anderson (1976) and Lee and Focht (1975, 1976b). For the slope stability analysis, it may be convenient to use the cyclic earthquake loading data in terms of the reciprocal of the factor of safety:

$$1/F = \tau_{max}/S_u$$

where $_{max}$ is the maximum shear stress in the slope sediment produced by the largest pulse in the designated quake, and S_u is the static strength in an undrained test performed on an undisturbed sample prior to any cyclic loading.

Two 'undisturbed' relatively long (4 and 8 m), large diameter (8 cm) cores suitable for geotechnical testing were obtained from the creep area. Special techniques were applied in order to successfully carry out geotechnical testing on the very soft sediments. These tests included the evaluation of the index properties of the sediments (granulometric analyses: 50-70% clay size fraction less than 2 um; average grain specific gravity, 2.78; average unit weight, 1.5 g/cm^3; average water content, 90%; average porosity, 75%; liquid limit, 80-95%; plasticity index, 50-60%), the consolidation properties (compression index, 0.50-0.75; coefficient of consolidation, $0.6.10^{-4}$–2.10^{-4} cm^2/sec; average preconsolidation stress 0.1 kg/cm^2; earth pressure coefficient at rest, 0.54) and shear strength (undrained laboratory vane tests, $c_u/\bar{p}_u$ = 0.24-0.33, and sensitivity of 3; consolidated undrained triaxial compression tests, ϕ_{cu} = 15-17°). Experiments to carry out the complicated triaxial compression tests under cyclic loading were successful, and the results of the few tests that were made, indicate the weakening effect of the repeated loading on the strength properties of the sediments. Analysis of the earthquake effects on the stability of these sediments will be made in light of the results of these tests.

References

Alamgor, G., 1976. Physical properties, consolidation process and slumping in recent marine sediments in the Mediterranean continental slope of southern Israel. *Isr. Geol. Surv., Rep.* MG/76/4, 132 p. (in Hebrew).

Almagor, G. and Wiseman, G., 1977. Analysis of submarine slumping on the continental slope of the southern coast of Israel. *Mar. Geotech.*, vol. 2, pp. 349-388.

Amiran-Kallner, D. H., 1950. A revised earthquake catalogue of Palestine, I. *Isr. J. Expl.*, vol. 1, pp. 223-246.

Anderson, K. H., 1976. Behaviour of clay subjected to undrained cyclic loading. *Norg. Geotek. Inst., Publ.* 114, pp. 33-44.

Lee, K. L. and Focht, J. A., 1975. Liquefaction potential at Ekofisk tank in the North Sea. *Am. Soc. Civ. Eng., J. Geotech. Eng. Div.*, vol. 101, pp. 1-18.

Lee, K. L. and Focht, J. A., 1976a. Strength of clay subjected to cyclic loading. *Mar. Geotech.*, vol. 1, pp. 165-168.

Lee, K. L. and Focht, J. A., 1976b. Cyclic testing of soil for ocean wave loading problems. *Mar. Geotech.*, vol. 1, pp. 305-325.

Neev, D., Almagor, G., Arad, A., Ginzburg, A. and Hall, J. K., 1976. The geology of the southeastern Mediterranean. *Isr. Geol. Surv., Bull.* 68, 51 p.

Thiers, G. R. and Seed, H. B., 1969. Strength and stress-strain characteristics of clays subjected to seismic loading conditions. *Proc. Symp. on Vibration Effects of Earthquakes on Soils and Foundations, Am. Soc. Test. Met., Spec. Tech. Pub.*, 450, pp. 3-56.
Willis, B., 1928. Earthquakes in the Holy Land. *Seismol. Soc. Am., Bull.*, vol. 18, pp. 73-102.

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GEOCHEMISTRY AND SEDIMENTOLOGY OF THE DEAD SEA

Yitzhak Levy

The research program in the Dead Sea, which started in 1978, includes the following subjects:

1) Seasonal changes in chemical composition of Dead Sea waters

During the winter of 1979/80, which was a particularly rainy one, large volumes of fresh floodwaters flowed to the Dead Sea between December 1979 and April 1980. The floodwater mixed with the surface Dead Sea waters down to a maximum depth of 25 m and led to the formation of two water masses: an upper diluted one ranging in chloride concentration from 170 to 225 g/l and a lower water mass with about 230 g/l. In stations 3, 4 and 5, the interface between the two water masses was at about 10 m during the period from April to May with no measureable fluctuations. Stations 1 and 2 showed a different pattern in that just after the floods dilution was maximal (170 g/l chloride) and the upper diluted water mass extended to a depth of 25 m. This is believed to be due to the location of both stations close to the beach; furthermore, station 1 is located in the rather restricted Lisan Straits.

The stratification was maintained from December 1979 to August 1980. Further measurement will show whether this stratification will be maintained through the fall and, in case of another rainy winter, on through the winter months. The minimum volume of floodwaters for 1979/80 was estimated at about 1.4 km^3.

2) Seasonal and long-range changes in oxygen and hydrogen sulfide concentration in the Dead Sea

Oxygen concentrations in the Dead Sea in 1979/80 show different patterns compared to those reported by Neev and Emery (1967) measured in 1959. As against the depleted water column below 40 m (0.1 - 0.2 ml/l) reported in 1967, in 1979/80 all of the water column contains considerable concentrations of oxygen (0.7 - 0.9 ml/l).

Seasonal changes in oxygen content are dictated both by dilution which leads to an increase in oxygen concentration up to 2 ml/l in surface water in March 1980 and by biological activity which may lead to either a decrease in oxygen content, e.g., 1.2 ml/l in May against 2.0 ml/l in March for surface water or to an increase in oxygen content during periods of blooming of algae and enhanced photosynthesis as was the case in August 1980 (an increase in oxygen from 1.2 in May to 1.8 in August for surface waters).

Mixing leads to similar profiles in May for different stations while the same stations showed dissimilarities in oxygen profiles a few days after the March flood.

Hydrogen sulfide which ranged from 7 to 17 ml/l in 1959 (Neev and Emery, 1967) is absent from the water column. Near bottom waters contain trace amounts of hydrogen sulfide (a maximum of 0.05 ml/l).

3) Recent halite precipitation in the Dead Sea

Enrichment of magnesium, sodium and chloride in the Dead Sea as a result of evaporation during the period from 1959 to 1977 was used as a parameter for calculation of losses in water volume of the Dead Sea during the same period. Using volume balances of water in the Dead Sea during the periods 1959-1977 the rate of evaporation is calculated to be about 1.8 km^3/year. Comparison of the enrichment factor for magnesium, 1.08, caused by evaporation only, to the enrichment factor for sodium during the same period, 1.02 and the Na/Cl equivalent ratio for 1959 to 1977, clearly shows that sodium was precipitated from Dead Sea water as halite.

Mass balance for sodium shows that about 450 to 520 million tons of halite were precipitated from Dead Sea water (excluding precipitation in Dead Sea ponds and as "salt reefs") of which only about 30 million tons were found in the sediments of the northern basin. The additional 420 to 490 million tons of halite probably precipitated in the eastern portion of the southern basin. Efficient circulation of brines from the southern basin to the northern basin till 1977 is suggested, since