General report/Discussion session 7: Collapsible and swelling soils – Part 1: Collapsible soils

Rapport de spécialistes/Séance de discussion 7: Sols collapsibles et sols gonflants – Première partie: Sols collapsibles

W.R. MACKECHNIE, Civil Engineering Department, University of Zimbabwe

GENERAL: The purpose of a general report at our international conferences is seen as serving the following purposes.

Reviewing the papers submitted to the conference session and commenting upon these with particular reference to the discussion which they should provoke. There are fifteen papers dealing with collapse conditions and three papers with collapse or swelling applications

Reviewing those aspects of the technical committee's work in the inter conference period of four years in terms of the items for discussion which have arisen during that time. In this instance the Conference "Engineering Problems of Regional Soils" held in Beijing, China, in August 1988. In that conference there were two invited lectures and thirty five papers on the topic of collapsible soils.

Noting other published material on the topic during the intervening four years. In particular "The State of the Art Report - Collapsible Soils" by Schwartz.(1985)

Making an evaluation of the current state of the art in a concise form. The objective being to stimulate discussion in those areas of the topic which will permit the discussion leader, the panellists, and the contributors from the floor to make the best use of the time set aside for this purpose in the current session.

Before proceeding to the detailed consideration of the papers presented it is considered essential to state the approaches adopted in defining collapse in the context of the soil types involved and the collapse phenomenon as opposed to the established approach to consolidation settlement.

1 THE SOIL TYPES LIABLE TO EXHIBIT COLLAPSE

Soils with dry unit weights below $16kN/m^3$ which are partially saturated either on a continuous basis or seasonally are suspect. Not all soils with low unit weights are necessarily collapsible, but partial saturation is generally a prerequisite to collapse. The soil type and geological source material can vary widely. The division of soils into either transported or residual soils in terms of their origin is important. Both transported and residual soils can exhibit collapse. The common feature will be a collapsible fabric in the soil structure which will be associated with relatively high permeability.

Collapse can occur in soils which are over consolidated as well as in the more usual normally consolidated cases. The anticipated collapse in a particular soil will be smaller in the overconsolidated range than in the range immediately above the preconsolidation pressure

The purely aeolian sands, while liable to exhibit some collapse, are less of a potential problem than materials such as loess which by definition is considered to be a transported soil but,having had a content of weatherable material, has subsequently developed a collapsible fabric which will exhibit substantial collapse when loaded and thereafter saturated.

The residual soils which exhibit substantial collapse are generally those which have been highly leached in situ. The source rock type can be extremely variable. The common factor, however, is the presence in the parent materials of weatherable minerals in the environments to which they have been exposed subsequent to their formation in geological time.

2 THE TRIGGER MECHANISMS CAUSING COLLAPSE

The concept of a soil stable with respect to its current environment is an important starting point to accept. The changes which can give rise to collapse are first loading by a structure or by dynamic forces and then a subsequent trigger effect due to saturation or near saturation. In some instances dynamic or seismic loading may provide the trigger effect. The question of liquefaction in the latter events are debatable cases of collapse in your reporter's opinion.

3 THE COLLAPSE PHENOMENON

Collapse is by implication sudden and of significant magnitude. It is not immediate settlement, primary consolidation settlement nor secondary consolidation. It generally occurs as the result of increase in moisture content and thus the expulsion of air from the collapsible soil fabric rather than expulsion of water. There is always the possibility that subsequent to the collapse and the transition to the near saturated state that consolidation will follow collapse in the transformed soil structure which will then exist. It is stressed that collapse is a phenomenon which only occurs subsequent to loading and subsequent to the change in conditions in situ which produce it. It is not readily equatable to the reduction in shear strength of a partially saturated soil based on Bishop's equation for effective stress in which pore air pressure is differentiated from pore water pressure

$$\sigma' = \sigma + \chi(U_a - U_w) - U_a$$

There may, however, be occasions when this approach is correct and applicable. This is certainly an area where additional research is warranted despite the relatively intractable nature of the problem.

Collapse can thus occur many years after construction prior to which a structure will have performed perfectly satisfactorily.

4 REVIEW OF THE PAPERS PRESENTED TO THE 12th ICSMFE

The purpose of this review is to group the papers together in terms of the related aspects of the topic to indicate the subject matter covered. It also suggests the areas for discussion at this conference. In addition it indicates the topics for future research and practical applications.

5 IDENTIFICATION OF SOILS LIABLE TO COLLAPSE

Huergo et Al (1989) describe the problems arising from inundation of the foundation soil beneath a thermal power station cooling tower in Northern Greece. A typical case of well graded materials which do not fit into the preconceived gradings of collapsible soils. The existence of layers at high insitu void ratios eo = 0,87 and low degrees of saturation 68% are noted and should have been a warning to the original designers. The need to anticipate collapse in such conditions and not to rely on soil gradings and index properties has been noted for some considerable time Mackechnie (1967). The current case emphasises the need to stress this point to foundation designers.

The value to city planners, developers and designers is well illustrated by Ali et Al (1989) with regard to the occurence of collapsible soils in Tucson, Arizona. The application of statistical methods to the rationalisation of the inevitably random results of the soil properties and test results over a substantial area is worthy of study and would be enhanced by additional input from other cities. The collapse criteria used and the soil properties considered were the conventional ones. The value of the work will be in indicating the need or otherwise of site specific investigations for particular projects.

Stepkowska (1989) deals with the results of laboratory investigations of smectite particles. The arrangement of these particles, the tendency for delamination to occur and the possibilities of collapsible structures deforming is discussed in relation to bentonites.

While this study is of a microscale nature it appears to have particular relevance to the study of the postulated clay bridges between quartz particles in the leached and weathered potentially collapsing soils.

6 LABORATORY AND FIELD IDENTIFICATION TESTING

Signer et Al (1989) catalogue the results of collapsible and expansive soils at the Itaparica Lake settlement and irrigation scheme in Brazil. Only the collapsible soil aspects are commented on here. The results indicate typical occurrences in terms of increased moisture contents due to irrigation practices and increased population pressures. Predictably soils with unit weights below 16 kN/m^3 invariably did so. The area's semi arid climate and seasonal rainfall coupled with low unit weights were clear predictors of collapse potential. The solutions adopted using prewetting and compaction have proved completely successful for single storey housing elsewhere and should be equally applicable on this project and confirmation of this by the authors is awaited with interest.

7 THE COLLAPSE PHENOMENON

In his contribution to this conference, Grigoryan (1989) highlights the effects of a percolating saturation front in a potentially collapsible profile. He seperates subsidence which occurs into three stages, "initial accelerating", "active" and "stabilizing decelerating" and shows good correlations between field measurements and analytical data. The effects of changes in ground water levels which have not previously occurred are shown to contribute to additional settlement of a collapse type and this should be particularly stressed.

8 LABORATORY AND FIELD TECHNIQUES

El Sohby et Al (1989) studied the problem of collapse in cemented sands and emphasise the difficulty in obtaining satisfactory samples in the field. The laboratory techniques developed were refined and errors by comparison with plate loading results were reduced by using larger sample diameters. Discussion on the applicability and quantification of plate loading tests in relation to the potential for collapse of full scale structures would be a valuable contribution to this session. The contribution of soluble salts to increased stability at low environmental moisture contents is becoming an area of particular interest in the central latitudes of Europe and Asia where calcium salts and in particular gypsum reinforce an otherwise collapsible fabric. Petrukhin (1989) gives examples of soils with up to 50% of easily soluble salts which, when they occur in soils of low unit weight and low initial moisture content, will contribute to a complete breakdown of structure on subsequent saturation. The paper differentiates between sandy loams and loams. It shows that for the former at low gypsum contents, 10-30%, and low effective stresses, 100-300kPa, that these soils will exhibit significantly lower collapse settlements than do the loams with the higher clay contents. Such soils will occur in loess with the higher clay contents. Such soils will occur in loess formations and partially cemented sands in arid and semi arid regions. Discussions and contributions of relevant case histories are particularly encouraged in this topic area.

9 TRIGGER MACHANISMS

The trigger mechanism of saturation or a degree of saturation leading to the occlusion of continuous air voids appears to be generally accepted by all authors. The value of the latter is generally considered to be about 85% saturation coinciding with saturation at optimum moisture content for most compactive efforts. Peaker and Ahmad (1989) deal with the case of pile driving triggering subsidence. This is an interesting case history and warrants debate with particular reference to deciding whether to classify the event as rapid consolidation or collapse. The dynamic loading due to the pile driving obviously triggered the event but the egress of water in holes penetrating the upper profile is possibly indicative of occlusion of a potential artesian condition which when drained has actually resulted in rapid consolidation as opposed to collapse.

10 ENGINEERING APPLICATIONS TO REDUCE OR PREVENT COLLAPSE

Several papers deal with developments in areas where the soil profile has previously been assessed as potentially collapsing. The approach to providing a satisfactory foundation system on such profiles can most readily be divided into three areas.

1 Surface compaction techniques
2 Penetration coupled with deep compaction procedures, and
3 The compaction insitu of fills to ensure that the resultant fill is not subject to collapse settlements.

Riani & Barbosa (1989) deal with the compaction by wetting and rolling which provided satisfactory founding conditions for light structures. The heavy structures and bridge foundations were carried down to firmer materials at depth. The potential for collapse brought about by wetting up due to irrigation and canal systems was of particular relevance. Ferriera and Teixeira (1989) deal with the construction of 1856 units of high density low cost housing and where one foundation solution adopted was the use of short bore piles. While the laboratory tests confirmed the potential for collapse the plate bearing tests in the field were inconclusive in your reporter's view as the trigger state for collapse was not necessarily produced. Further information on the behaviour of those houses founded on short bored piles,in comparison with those on strip footings on compacted substrata, would be of value as would any comparative costs for the alternative techniques.

Abelev et Al (1989) present a wide and well documented contribution on soil improvement in deep profiles of loess. The problems of compaction of considerable depths of soil and the results for dynamic compaction and the use of earth/stone piles are dealt with. There is a valuable contribution, in terms of the detailed procedures adopted for the use of explosive charges, soil inundation and tamping in of stone. The assessment of the improvement achieved by field observations of increased density and resulting overall surface settlements provides an encouraging demonstration of the benefits achieved. The reduction in pile bearing capacity due to negative friction in a collapsible profile is a point well made and elaboration of these techniques and findings should prove a fruitful area for discussion. Liausu and Veraskin (1989) give details of the improvement to soil densities attainable with dynamic compaction. They quote 10% increase in density for soil at an initial unit weight of 14,7kN/m^3 for average energy inputs of 150tm/m^2. The cost and benefits of dynamic compaction still appear to be an area of uncertainty and contributions to topic will be welcomed. Farkas & Kovacs (1989) deal with bored piles in refuse dump fills where the concrete for the piles has fly ash as the cementitious agent. Ultimate concrete strengths slightly in excess of 5MPa were obtained and the findings that negative skin friction could be neglected after 10 years had elapsed since the placing of the refuse is of particular interest. Flooding tests did not produce collapses of the magnitudes anticipated, although collapse occurred to some extent. The finding that the fly ash bored pile provides a satisfactory and economic founding system is worthy of note and the observed and predicted settlements call for discussion.

11 EMBANKMENTS AND FILLS

The subject of fills is dealt with by Lefebvre and Belfadhel (1989) on the basis of the amount of collapse which is likely to occur if particular compaction approaches are used. They clearly illustrate that at moisture contents below optimum the anticipated settlements on saturation will be greater. They thus effectively confirm the results which are attainable by double oedometer testing. The quantification of percentages of collapse to be anticipated at low values of standard Proctor maxima are of interest and debate on these values is encouraged. Miranda and Van Zyl (1989) in their finite element approach to collapsing soils consider small earth dams in which their developments of a constitutive approach utilises pore air pressure and pore water pressure.

Delage (1989) presents a case history which deals with a bridge approach embankment compacted too dry and thus too loose. The field and and laboratoryobservations are concordant and well demonstrate the collapse type settlements which can result.

12 MATHEMATICAL APPROACHES

Amirsoleymani (1989) considers the distribution shape and size of macropores in Iranian collapsing soils on a mathematical basis and suggests basic formulae for coefficients of collapse for four zones in Iran. He compares these with typical soil properties in potentially collapsing areas in China, Saudi Arabia, the USA and Bulgaria. By assessing the various properties which can contribute to collapse, this paper illustrates that the mathematical fit to laboratory results can be good. Applications of the theoretical approach alone, without confirmatory laboratory tests, would appear to permit a rather wide range of estimates of collapse and discussion on this topic is certainly warranted.

The finite element method approach for collapsing soils presented by Miranda and Van Zyl is applicable to earth dams. In such situations embankments subject to saturation, the shear strength approach to collapse is most appropriate.

The comparison of well compacted embankments with poorly compacted ones uses (σ -U_a) and (U_a-U_w) to define the stress strain relationship and illustrates the likelihood of hydraulic facture occurring leading to piping failures. While the mathematical approach is convincing, the possibility of the soils in situ being dispersive in the poorly compacted state needs examination and arguments on this point appear appropriate. The stress paths followed as the water flow advances through the dam cross sections in this paper is a clear demonstration of the flexibility of the finite element method and constitutes an interesting advance in analysis.

Karube and Kato (1989) deal with yield functions in unsaturated soil. They present suggested solutions on a compacted kaolin clay which could have relevance for both potential collapse and potential heave in applications to real soils. Development of this theme by the authors would be welcomed.

13 THE SESSION ON COLLAPSING SOILS IN THE CONFERENCE "ENGINEERING PROBLEMS OF REGIONAL SOILS", BEIJING 1988

The invited lecture by M.Y.Abelev (1989) was a vivid state of the art report on the practice of construction on loessial soils in the USSR. Depths of soils with collapsible fabrics of up to 75m were dealt with. The techniques of pre-collapsing the profiles coupled with the use of explosives on a major scale was described. Recompaction of "shallow" profiles up to 12m thick indicate the difficulties faced and the explosives involved. Point of particular interest were quoted, for instance -

(1) The assessment that any loose soil below the 80% saturation value is potentially collapsing.
(2) That concrete piles should not be used unless they can fully penetrate the collapsible profile.
(3) That earthern piles of compacted loess will work well and can be carried down to depths of 50 to 75m.
(4) The use of injected grouts, such as silicates, is only practicable in a porous fabric and is generally too expensive to contemplate as an alternative to other methods, except when undertaking remedial repairs.

The information given is a particularly valuable catalogue of established practice and proven techniques.

Quian and Lin (1989) in the second invited lecture gave a comprehensive overview of the occurrence, properties and problems arising on the loessial soils of China. The upper loess which exhibits collapse under the existing overburden pressure when flooded can produce subsidences of up to 10% of the profile thickness. Good correlations were obtained between the calculated collapse on saturation and actual collapse. The actual values were generally higher. The code of practice in China gives a value of 1,5% as the limit for the coefficient of collapse above which collapse is likely to occur on saturation. The pressure at which this value is reached usually coincides closely with the saturated preconsolidation pressure of the loess. The design and application techniques used in China have covered the whole range of dynamic compaction, chemical injection, flooding, explosive detonation, lime and stone columns, bored and hand dug piles, precast piles and compacted soil cushions.

The constraints of space and time do not permit even a scant review of each of the thirty five papers contributed to the conference but an attempt to highlight some novel features and significant aspects follows:-

Andrei and Manea (1989) discussed the concept of under consolidation at porosities of 48% to 52% and concluded that a vertical wetting front produced an integrated progressive collapse, while horizontal wetting tended to die out as one would anticipate.

Antonescu (1988) stated that 17% of the area of Romania was covered by loess. The vertical permeability was found to be several times that of the horizontal permeability. This paper is a very thorough and detailed statement of practice in that country giving considerable information on the use of sodium silicate grouting, electro osmosis, controlled wetting and undermining rehabilitation approaches which should be a facet of our discussions.

Bagdasarov et Al (1989) dealt with assessing negative skin friction on piles adjacent to ponded water sources. They found values of 50kPa close to the water source with reductions down to 20kPa some 20m distant.

Chen (1989) dealt with loessial foundation soils in dam projects. Considerable depths of excavation were quoted, up to 49m being recompacted in one case. Prewetting was used successfully and hydraulic fills using loess at dry unit weights of 14,4kN/m^3 gave satisfactory impermeability down to 10^{-8}m/s. Settlements during construction in one case amounted to 469mm followed by 259mm during impounding, total 728mm.

Deal and Smith (1989) dealt with the use of cone penetrometers and borehole pressure meters in establishing soil parameters for finite element analyses to study collapse phenomena in alluvial fans in the S.W. of the United States. The modelling proposed appeared most promising and an important field finding was that soil stiffness did not necessarily increase with increase in depth.

Modelling using triaxial test data was dealt with by Dong and Liu (1988). While Feng and Feng (1988) investigated collapse sensitivity. Using data from 500 tests they postulated values close to those established by others. Fodor and Angheluta (1988) described a capping layer of soil stabilised with blast furnace slag and quick lime which proved successful as a soil cushion in Romania.

Ilyichev et Al (1988) described the Russian experience with chemical grouting using liquid and gaseous methods. Considerable improvements are claimed. More details of equipment and processes would have greatly enhanced a very interesting treatise.

Huergo and Crespo (1988) describe the loessial soils of Belgium and in a later paper Huergo (1989) has further developed these findings. In Belgium's wetter environment they show that collapse is reduced when a soil at a moderately high moisture content and saturation will have undergone consolidation to a large extent, thus leaving only a small additional collapse to occur on final full saturation.

Pore size as a criterion for establishing collapse potential was dealt with by Lei (1988) and merits comparison with Stepkowska (1989).

Moll et Al (1989) described loessial soils in Northern Argentina indicating particular concern for the possible adverse effects of intensified seismic activity in the region. More information on collapsible soils in that area would be of value and very appropriate at this conference.

The effects of seismic events in China on slopes in loess and on buildings founded on such soils is obviously an important field for research,as indicated by Zheng and Zhang (1988). Water contents below 10% produced stable conditions, while induced stresses below 20kPa did not cause subsidence. However, in the stress range 20kPa to 50kPa problems began to manifest themselves.

Xu (1989) dealt with stabilisation of saturated loess by carbon dioxode gaseous injections followed by sodium silicate solution and a second series of carbon dioxide injections. These investigations confirmed the increased efficiency of this method and the significant reduction in time to attain stabilization which results.

Tu (1989) compared chemical grouting using caustic soda with sodium silicate grouting in stabilising the Shaanxi Coking Plant and considered it cheaper, more effective, and less likely to produce additional settlements. Subsequent injections of calcium chloride were used in some cases.

14 THE STATE OF THE ART REPORT BY SCHWARTZ(1985) AND THE DEVELOPMENT OF THE STUDY OF COLLAPSE IN SOUTHERN AFRICA

This report traces the development of the study of collapsible soils in Southern Africa from the initial publications by Jennings and Knight(1957) through to 1985. Initially the soils were considered to be largely arenaceous Knight(1963). This was queried by Mackechnie(1963). Subsequently, in a speciality session,Mackechnie (1967), Jennings confirmed collapse conditions could also occur in soils derived from argillaceous parent materials. Next In response to the general report Mackechnie (1971) Knight proposed a single test saturating the potentially collapsible material at the design foundation bearing pressure. It was noted that certain soils could exhibit heave at low effective stress on saturation but would be liable to collapse at higher effective stresses.Jennings and Knight (1975) produced a valuable contribution which was the current state of the art and noted four signficant misconceptions which required to be dispelled.

In reviewing Schwartz(1985) at this stage of this general report one finds that he well appreciated all the areas of current research and applications and that the contributions in the past four years are recording advances in detail rather than presenting new breakthroughs. The assessment of the current state of the art thus tends to be a reemphasis in many areas in addition to noting advances, notably those dealing with deep deposits of loess.

15 COLLAPSIBLE SOILS IN 1989 AND IN THE IMMEDIATE FUTURE

The identification of collapsing soils is now clearly established. The quantification of the collapse settlement can be estimated with reasonable accuracy. The double oedometer test and the single variant test with flooding at specified load intensities are still the best means of estimating collapse settlements. The engineering solutions adopted have remained the same but considerable advances have been made in ensuring their effectiveness. The use of dynamic compaction, stone displacement piles, explosions and similar techniques have been enhanced and refined, particularly in respect of the Northern Hemisphere loessial soils. The problems of costs and effectiveness of chemical grouting and vibroflotation techniques now more clearly indicate where they merit application.

The collapse phonomenon is still an area warranting fundamental research and this should be pursued. The soil fabric is being studied in finer detail and this may enable a better understanding to be achieved. The distribution of collapsible soils continues to be documented and needs to be kept in the forefront of foundation designers' consideration. Sampling difficulties are better appreciated and must be stressed to field workers and testing laboratories.

The importance of ensuring that value for money is obtained for low cost high density housing, lightly trafficked roads in a world of increasing population and diminishing per capita resources makes it imperative that the problems of collapsible soils are overcome with engineering design and site preparations which are economic, feasible and entirely satisfactory. Your general reporter believes that we have reached this stage but fully appreciates that we must continue to refine and develop and, most important of all, we must diseminate our knowledge. We need to appreciate that we must continue to ensure that upcoming generations of contractors, consultants and researchers are kept aware of the state of our art at close and regular intervals.

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