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I.M. Idriss: A Pioneer in Geotechnical Earthquake Engineering

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INTRODUCTION

This symposium was organized to honor our colleague I. M. Idriss for his many significant contributions to the discipline of geotechnical earthquake engineering. However Idriss did much more than contribute to geotechnical earthquake engineering. He was a member of that small group at Berkeley who in the mid-sixties began to lay the foundations of our profession and to establish the structure and processes of engineering practice in geotechnical engineering followed to this day. Two years ago at the EESD IV Conference in Sacramento (Finn 2008), I paid tribute to this remarkable achievement by dedicating my keynote lecture as follows:

This paper is dedicated to three men who laid the foundations for the development of geotechnical earthquake engineering in the 1960's and nurtured its growth by major contributions to teaching, research and practice over many years: the late Professor H. B. Seed of the University of California at Berkeley and his PhD students at that time, the late Professor Ken Lee of the University of California at Los Angeles and Professor I. M. Idriss, recently retired from the University of California at Davis.

The story of geotechnical earthquake engineering as a focused discipline and the role of Idriss in its development began in 1964 in the aftermath of two great earthquakes, The Alaska earthquake in March of that year and the Niigata earthquake in June. The Alaska earthquake posed very difficult problems for engineers involved in reconstruction. They needed a better understanding of the phenomenon of liquefaction and its effects on slope stability, foundations of structures, retaining walls, pile foundations and bridges. Major examples were the Seward Slide, the Turnagain Heights failure, the L-street slide in Anchorage (National Academy of Sciences 1973). The need for understanding was ably expressed by President Lyndon Johnson in a directive to his Special Assistant for Science and Technology, Donald F. Hornig:

"It is important we learn as many lessons as possible from the disastrous Alaskan earthquake. A scientific understanding of the events that occurred may make it possible to anticipate future earthquakes, there and elsewhere, so as to cope with them more adequately".

The Niigata earthquake was very important to the Alaskan study of earthquake damage because there was much more quantitative data available for the Japanese sites, including, for the first time, ground motion records from a liquefied site. This became an important case history in a later validation study by Seed and Idriss (1967). The importance of Niigata was enhanced by the close cooperation between the Berkeley group and Japanese researchers.

Responding to the need for a better understanding of liquefaction problems, the late Professor H. B. Seed established a major research program at the University of California at Berkeley. In his research he was ably assisted by two outstanding graduate students with the complementary skills needed, I.M. Idriss, the analyst, and the late Ken Lee, the experimentalist. I was fortunate enough to be visiting professor at Berkeley in 1964 and returned the following summer for four months. These were very exciting times. It was a stimulating experience to see three talented researchers with an ideal combination of complementary skills grapple with developing an understanding of what happened in Alaska and Niigata. I can clearly remember Idriss's struggle to duplicate the mechanics of the L-Street slide and the initiation of failure at Turnagain Heights and Ken Lee's efforts to replicate liquefaction in the triaxial test. My experiences at Berkeley changed my professional life.

On my return to the University of British Columbia, I gave up my research in plasticity and started the geotechnical earthquake engineering program there. I view that development as a further significant contribution by Idriss and his colleagues!! Over the years, I maintained a close friendship with Professor Seed and from about 1985 on with Professor Idriss. These Associations have given me the background and understanding to sketch the role of Professor Idriss in the development of geotechnical earthquake engineering.

YEARS OF DEVELOPMENT

In the mid-60's the only method of analysis available for estimating the seismic shear stresses induced in the ground by an earthquake was a visco-elastic model with a arbitrarily assigned viscous modal damping ratios. This type of analysis was first applied by Seed and Idriss (1967) to the Kawaguchi-cho liquefaction site in Niigata for which recorded motions were available. They were successful in simulating adequately the ground motions prior to liquefaction. These analyses were total stress analyses and were unable to predict directly the seismic pore-water pressures. These had to be inferred from the results of cyclic triaxial tests which were conducted with uniform stress cycles. Therefore it was necessary to represent the effects of the irregular time history of seismic shear stresses by an equivalent number of uniform stress cycles. The first version of this procedure was published by Seed et al., (1975). This development was crucial for the use of laboratory triaxial test data for assessing liquefaction potential from calculated seismic stress histories. Later this concept of equivalent cycles was extended to the estimation of displacements in earth dams (Seed et al., 1975a, b)

In the mid-60's, very few engineers had the programs or the ability to run site response analyses. Idriss, in one of his not infrequent creative moments (Fig.1), came up with the concept of the simplified method for estimating the average cyclic shear stress caused in a soil layer by a design earthquake. This shear stress was determined by assuming that the soil column above a depth of interest was rigid and acted upon by the peak ground acceleration. The deformability of the soil was taken into account by a depth dependent modification factor. The depth dependence was established on the basis of many site response analyses for different sites and using different input earthquake motions. The duration of shaking by this average stress was taken into account by using a number of equivalent cycles which depended on earthquake magnitude (Seed and Idriss, 1971). The simplified method made the evaluation of liquefaction potential a practical reality for engineers.

Fig. 1. I. M. Idriss having a creative moment.

Initially the evaluation of liquefaction was based on triaxial test data using reconstituted test samples. Later it was discovered that the liquefaction resistance from triaxial test data depends significantly on how samples are formed; by pluviation in air or water or by tamping moist sand samples. The alternative of testing field samples had problems also. It was impossible to get undisturbed samples of the looser sands typical of liquefaction sites. These problems encouraged long term research into the use of in-situ test data for characterizing liquefaction resistance. The first comprehensive regression of SPT and CPT data with liquefaction resistance was presented in an EERI monograph by Seed and Idriss (1982). This topic has been a lifelong interest of Idriss. In 2008, Idriss and Boulanger produced another EERI monograph on soil liquefaction, entitled *Soil Liquefaction during Earthquakes*, which is rapidly becoming the de facto state of the art manual for the assessment of liquefaction potential. This monograph is based on a comprehensive, critical evaluation of published research on the assessment of liquefaction potential and the evaluation of case histories and makes clear and unequivocal recommendations on what the authors consider the most reliable procedures for engineers in practice to apply to various aspects of the liquefaction problem. It updates all aspects of the simplified method. I believe that this monograph will join the small and select list of the classical texts in geotechnical engineering such as Terzaghi's *Erdbaumechanic,* Taylor's *Soil Mechanics* and Terzaghi and Peck's *Soil Mechanics in Engineering Practice.*

It quickly became evident that the visco-elastic soil model used in response analyses up to about 1967 was inadequate for modeling the nonlinear behavior exhibited by soil under strong shaking. The search for a simple but effective method for modeling non-linear soil behavior culminated in the brilliant concept of the equivalent linear solid. The concept rested on the work of Seed and Idriss (1970) on strain compatible moduli and viscous damping ratios. The concept was first encoded in the 1-D program SHAKE (Schnabel et al., 1972 which today is still one of the most commonly used programs in geotechnical earthquake engineering for site response analysis.

The finite element method of analysis for dams and slopes was introduced in 1967 (Clough and Chopra, 1966; Finn, 1966a, Finn and Khanna, 1967). Idriss made a big contribution by introducing variable damping finite elements (Idriss et al., 1974). This development was incorporated in the program QUAD-4 (Idriss et al., 1973).

By 1973 the essential components of geotechnical engineering practice had been developed. Reliable procedures had evolved for conducting cyclic triaxial and simple shear tests. Liquefaction assessment procedures by the simplified method or by analytical methods were firmly anchored to in-situ SPT data. SHAKE and QUAD-4 programs were readily available for seismic analysis that used soil properties such as modulus and damping familiar to all engineers. Although the picture was not yet complete (issues such as effective stress analysis were still in the future), the profession had a robust set of tools for tackling many seismic problems. Only one thing was lacking, a really convincing case history to demonstrate that the whole package worked in practice. The 1971 San Fernando earthquake provide the missing link with the near total collapse of the lower slope of the Lower San Fernando Dam.

Analysis of the slide in the Lower San Fernando dam is one of the most comprehensive case histories available (Seed et al., 1973, 1975a, b). It involved extensive triaxial testing, detailed studies of many SPT –N values, a post factum theoretical reconstruction of the slide by restoring slide blocks to their original positions and dynamic analysis of the dam by QUAD-4. The computed time histories of shear stresses in finite elements were converted to equivalent cycles of average uniform shear stresses. This conversion allowed peak pore water pressures and peak strains in the corresponding finite elements to be estimated from triaxial test data. The pore water pressures were incorporated into stability analyses of the failed slope. The displacements of the dam due to the effects of the earthquake were estimated from the element strains. The analysis predicted a large liquefied zone in the dam leading to failure and very large displacements, in agreement with what happened. The analysis of the San Fernando dam was a convincing validation of the utility of the tools developed by Seed, Idriss and their colleagues for geotechnical earthquake engineering practice.

YEARS OF CONSOLIDATION

By 1980 all the tools required for engineering practice had been developed to a level consistent with the technology of the times and the state of development of engineering mechanics and computer capability. Truly original developments became considerably more difficult to achieve. An era of improvement and consolidation set in. There were two exceptions to this, the advent of centrifuge testing and development of constitutive modeling. Professor Idriss gave his attention to centrifuge testing at the University of California at Davis. He assembled a brilliant group of researchers and together they developed one of the great centers for centrifuge testing in the world. The center is especially noted for major contributions to an understanding of the seismic response of single piles and pile groups in liquefied soils. The work of the Davis group on piles in sloping liquefied sites is of particular significance for bridge foundations. The centrifuge center is now under the capable direction of Professor Idriss's colleague, Professor Ross Boulanger.

Before 1985, a deterministic design earthquake of magnitude M was used in the estimation of liquefaction by the simplified method. The associated peak ground acceleration was determined by an appropriate attenuation relation. With the adoption of probabilistic ground motions there was no longer a unique earthquake magnitude associated with the specified design acceleration. It was the product of contributions from all earthquakes of many different magnitudes in seismic sources influencing the ground motions at the site. In these circumstances, what earthquake magnitude could be associated logically with the probabilistically derived peak ground acceleration? Professor Idriss (1985) introduced the concept of weighted magnitude probabilistic analysis to resolve this problem. In this approach, any normalizing magnitude, say M=7.5, may be selected and all other magnitudes are weighted with respect to it by the magnitude weighting factors commonly used in applications of the simplified method (Idriss and Boulanger, 2008). Then a probabilistic ground motion analysis is conducted to get the acceleration associated with the normalizing magnitude using a program such as EZ-Frisk (Risk Engineering, 2000).

As pointed out by Idriss (1985) the weighted probabilistic analysis can be done for any normalizing earthquake. For weighting magnitudes other than magnitude other than M=7.5 the appropriate magnitude weighting factor for the chosen normalizing magnitude must be applied when calculating liquefaction resistance.

The weighted magnitude probabilistic analysis is accepted in California as a procedure for implementing the requirements of the Division of Mines and Geology guidelines in DMG SP 117 for projects requiring review under the Seismic Mapping Act of California. DMG SP 117 states "The alternative approach calculating "magnitude-weighted accelerations" is considerably easier and it provides a unique magnitude to be used with the probabilistically derived accelerations" (SCEC, 1999).

The first definitive liquefaction resistance chart was produced by Seed and Idriss (1982) based on the limited data available at the time. Since then, many major earthquakes have occurred in USA, Japan, China, Taiwan, and Turkey which have contributed in a big way to the liquefaction data base. Idriss has been updating the basic Seed-Idriss liquefaction chart in response to this new information and has also developing up to date liquefaction charts based on the CPT

(Idriss and Boulanger, 2008). Many other aspects of the simplified method, particularly the depth modification factor, have been updated in the same publication.

In their 1982 EERI monograph, Seed and Idriss also presented the state of the art on design ground motions. Idriss has maintained a strong interest in this topic to this day. In February 2008, a new generation of attenuation relations was published by EERI based on research sponsored by the Pacific Earthquake Engineering Research Center (PEER) centered at the University of California at Berkeley that are having a major impact on code design motions and on site specific studies for geotechnical projects. One of these new attenuation relations is by Professor Idriss. (Idriss, 2008). These two major contributions in 2008, forty four years since he began his first studies in geotechnical earthquake engineering testify to the continuing creative vitality of Professor Idriss.

CONCLUSION

We have reviewed the research contributions of Professor Idriss over a 45 year span and shown how significantly these have contributed to the development of geotechnical engineering practice. But Idriss has also contributed to practice by his active role in high level consulting. He brings to review groups and boards of consultants the evolving state of current research and his own innovative concepts and solutions, greatly facilitating technology transfer to the profession. We thank and honor Professor Idriss for his contributions to our profession and we wish him many more years of fruitful practice.

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