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Cyclic response of saturated silts

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ABSTRACT

Softening and strength loss of sands with increasing excess pore water pressure under repeated loads is well-known. However, extensive damage to the built environment also occurs at the sites underlain by fine grained soils during seismic shaking. The primary objective of this study is to investigate the factors affecting cyclic behavior of saturated low-plastic silt through laboratory testing. For this purpose, an extensive laboratory testing program including conventional monotonic and cyclic triaxial tests was carried out over reconstituted silt samples. The effects of the inherent soil properties and the effects of loading characteristics on the cyclic response of saturated low-plastic reconstituted silt samples were examined separately. Based on the test results, a model was introduced to estimate the effect of initial shear stress on the cyclic response. Besides, liquefaction susceptibility of the samples was examined via current liquefaction susceptibility criteria.

1. Introduction

Response of saturated silty soils under repeated loads has been a point of interest particularly in the last decade due to the occurrence of widespread seismically induced damage to the built environment during recent large earthquakes over areas underlain by such soils. Owing to the differences between the mechanisms dominating the cyclic response of fine grained and sandy soils, the procedures used to estimate the response under seismic loads are distinct for the two general soil types. The evaluation of the response of silt, which comprises the borderline between sand and clay in gradational order, is somewhat more complicated than those that can be distinguished as sand or clay [1,2]. Although the information available in literature is still rather limited on the pore pressure build-up and the associated degradation of stiffness and strength of silts under cyclic loads, the response is reported to be dependent on a number of criteria including stress history, attributes of loading besides the material characteristics such as the plasticity index. Yet, the findings are often contradictory regarding whether the influences of such factors are beneficial or adverse on the response as well as their extents. Accordingly, the need is clear for further controlled laboratory studies to improve the present level of knowledge and to clarify the seismic behavior of silts as emphasized by Sanin and Wijewickreme [3] and Boulanger and Idriss [1].

Hence, a detailed laboratory testing program has been undertaken with the primary aim of improvement of the database for cyclic response of silts. The major part of the work consists of cyclic and monotonic triaxial tests conducted over silt specimens. The testing program is arranged so as to provide a systematic and controlled investigation of the factors affecting the behavior of silt on a comparative basis. For this purpose, to be able to eliminate the inherent variability due to natural deposition process, and to provide control over sample characteristics, reconstituted specimens are used in the study. Numerous researchers have reported earlier that the reconstitution procedure may have a substantial effect on the behavior of sands [4–6]. However, the information concerning the effect of reconstitution method on the behavior of silty soils in literature is rather limited. Accordingly, common reconstitution methods were examined. Taking into consideration the speed and ease of specimen production and that the saturated specimens are required, utilization of most of the reconstitution techniques is restricted. Consequently, slurry deposition technique appeared to be the most convenient for the reconstitution of saturated silt.

The undrained shear and deformation behavior of the saturated silt is investigated through a series of monotonic loading, and stress controlled cyclic triaxial tests conducted over isotropically and anisotropically consolidated soil samples. Undrained monotonic tests are performed to identify any conceivable relationship between monotonic and cyclic response of silt. To provide a profound understanding of the cyclic behavior on various parameters, the specimens are tested under a range of preconsolidation pressures, initial static shear stresses and initial confining stresses. During sample saturation pore pressure coefficient B of at least 0.95 is provided in all cases in the study.

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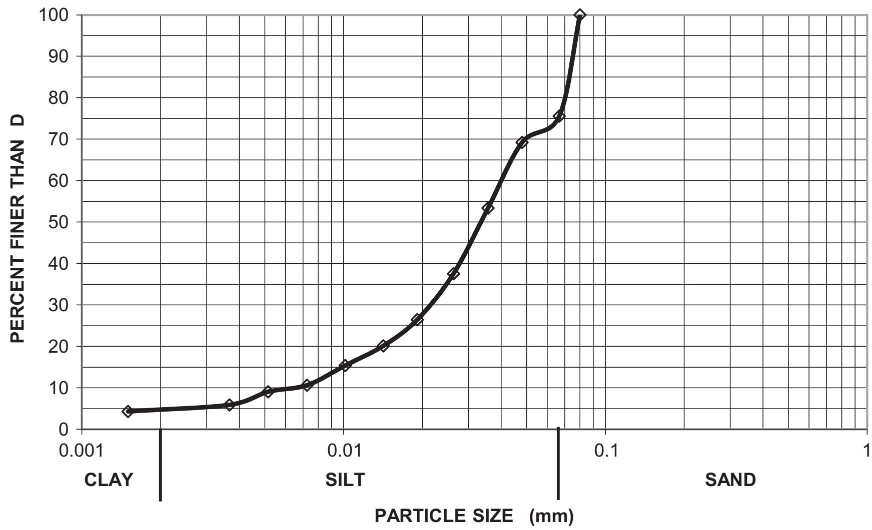

Fig. 1. Grain size distribution of the soil utilized in the study.

2. Properties of the reconstituted material and reconstitution process

The soil used in the tests was supplied in powdered form from Balad, Iraq. The grain size distribution of the light brown colored soil is presented in Fig. 1. The material consisted of 68.5% silt, 4.5% clay, and 27% fine sand size particles. The specific gravity is G_s=2.69, and Atterberg limits are determined as LL=31 (by means of Casagrande method), PL=24 and PI=7. The material is classified as low plasticity silt (ML) according to the Unified Soil Classification System (USCS), and plots adjacent to the A-line on the plasticity chart.

During the process of reconstitution, the material was mixed with de-aired water of an amount required to bring the water content to about 2 to 3 times that of the liquid limit. Hence, the workability is improved during the mixing process, and consequently homogeneous slurry is provided. The slurry was then placed into a box having dimensions of 19.5, 19.5 and 21 cm, inside of which was covered with a woolen fabric and provided with narrow drainage holes on the top and bottom covers. The box was then submerged in de-aired water and the slurry was consolidated under a vertical pressure of 40 kPa, which was imposed by means of a pneumatic piston. Following the consolidation, 16 specimens could be extruded from the box and the applied consolidation pressure was sufficient to produce specimens that are able to stand freely under their own weight. The recovered specimens were trimmed to the dimensions of 36 mm diameter and 71 mm height before being tested.

3. Monotonic triaxial compression tests

A series of undrained monotonic triaxial tests were conducted over the reconstituted samples to examine the response under monotonic loading, and to identify any conceivable relationship between monotonic and cyclic responses. An important issue during triaxial testing of fine grained soils is the rate at which the load is applied. Due to the friction at the two ends, distribution of stress and the strain is non-uniform along the specimen during loading. Sufficient time should be allowed during loading to provide stabilization of the pore water pressure within the specimen. Otherwise, the strength of the soil is affected by the non-uniformity of pore pressure. The monotonic triaxial tests were conducted at rates of strain ranging between 0.05 and 0.1%/min. The rates are determined utilizing the approach to ensure 95% of pore pressure stabilization in the specimen as proposed by Bishop and Hengel [7], and Germaine and Ladd [8].

Table 1
Initial states of stress and loading rates of monotonic tests.

Test	σ'_{1c} (kPa)	σ'_{3c} (kPa)	Initial p'_i (kPa)	Rate of ε_a (%/min)	OCR	e_i
ST1	35	35	35	0.1	1	0.74
ST2	50	50	50	0.07	1	0.72
ST3	50	50	50	0.07	2	0.71
ST4	50	50	50	0.07	4	0.69
ST5	80	80	80	0.07	1	0.73
ST6	75	75	75	0.05	1	0.74
ST7	100	100	100	0.07	1	0.72
ST8	100	100	100	1	1	0.71
ST9	100	100	100	1.4	1	0.71
ST10	80	50	60	0.07	1	0.72
ST11	100	50	66.67	0.1	1	0.75
ST12	100	50	66.67	0.1	1	0.76
ST13	120	50	73.33	0.1	1	0.77
ST14	90	60	70	0.07	1	0.73
ST15	120	60	80	0.07	1	0.74
ST16	140	50	80	0.1	1	0.74
ST17	150	50	83.33	0.07	1	0.75
ST18	160	50	86.67	0.1	1	0.72
ST19	200	50	100	0.07	1	0.73
ST20	120	80	93.33	0.1	1	0.71
ST21	150	80	103.33	0.1	1	0.73
ST22	120	100	106.67	0.1	1	0.69
ST23	150	100	116.67	0.1	1	0.68
ST24	180	100	126.67	0.1	1	0.70
ST25	200	100	133.33	0.1	1	0.70

Initial states of stress and applied loading rates for 25 strain controlled monotonic triaxial tests conducted on the reconstituted specimens are listed in Table 1. In addition to the tests performed with loading rates between 0.05 and 0.1%/min, two additional tests were carried out at a loading rate of 1.4 and 1%/min on the specimens isotropically consolidated under 100 kPa. Based on the test results, the average values of internal friction angle and cohesion were determined as 37° and 5 kPa, respectively.

Two specimens with OCR of 2 and 4 were monotonically tested as well. State of overconsolidation was achieved through unloading the specimens that were isotropically consolidated under 100 and 200 kPa, respectively. Accordingly, both OC specimens sustained 50 kPa initial effective confining stress prior to shearing. Those specimens were tested with a loading rate of 0.07%/min.