The Factors Affecting the Behaviour of Soft Soil Under Cyclic Loading in Railway

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ABSTRACT: The design of rail tracks is often challenged by the high compressible behaviour of soft estuarine clays under cyclic loading. In the coastlines of NSW and QLD in particular have very soft clays characterised by low bearing capacity and excessive settlement. Due to the ongoing pressure by the community to acquire high speed rail for greater commuter efficiency and faster heavy haul for improved mining and agriculture productivity, the need for detailed studies involving moving loads with high cyclic frequencies is paramount. In this study, apart from the general non-linear stress strain behaviour of soft subgrade soil, how the physical and mechanical properties are affecting the soft soil in terms of developing excess pore water pressure and axial strains under cyclic loading. The rates of degradation of the soil stiffness, the final resilient modulus and the damping ratio related to hysteresis have also been considered. Detailed experimental efforts and outcomes support the conclusion and the analysis should be carried out incorporating with the essential factors such as the cyclic stress ratio, frequency, number of cycles to failure, applied confining pressure, and principal stress rotation.

1 INTRODUCTION

The development of high speed train lines has grown widely all over the world, recently, due to the demand of increasing population and their needs. In order to achieve straight lines and lowering travel times, it is inevitable to cross the soft clay region. Most of the railway lines in Australia, specially NSW and QLD, have been constructed in coastal region especially on undesired soft soil (Attya, et al., 2007). Moving high speed trains induce continuous cyclic loading on the railway substructure (Li and Selig, 1998). The behaviour of the soft clay during moving loads is a most important problem in geotechnical engineering during the design stage of both railways and roadway (Carter, et al., 1979). Since soft soil has low bearing capacity and high compressible properties, performance of transportation structure affects significantly.

The failure strength in soft clay is well below the undrained shear strength obtained from standard monotonic tests (Andersen, 1976, Sangrey, et al., 1969). Accumulation of axial strain and rapidly generation of excess pore water pressure lead to failure since the effective stress approached to failure surface with number of cycles under undrained condition. Since the hysteresis behaviour of soft clay is nonlinear, the stress-strain characteristic of clay during the repeatable loads is not linear (Hardin and Drnevich, 1972, Thiers and Seed, 1968). It causes the degradation of soft clay with number of cycles varying respective value of frequencies.

The prediction of the behaviour of the stress path of cyclic loading in clay is strongly depended on the physical (Liquidity Limit, Plasticity Index, Water content and Grain size) and mechanical (Cyclic stress ratio, frequency, confining pressure and principal stress rotation) properties. In this paper, the essential factors affecting soft soil during high speed train will be discussed.

2 MECHANICAL PROPERTIES

2.1 *Cyclic Stress Ratio (CSR)*

High excess pore water pressure and axial strain are developed during the cyclic loading compared to static loading even if the value of cyclic loading is less than the maximum static loading. Researchers (Andersen, 1976, Sangrey, Henkel and Esrig, 1969) have used the tool as Critical Stress Ratio

(CSR) to show the level of cyclic stress without using absolute value. It is the ratio between cyclic deviator stress and static deviator stress at failure. However, since the static deviator stress at failure has no meaning unless the confining pressure is stated, Seed and Idriss(1971)defined the CSR as ratio between cyclic deviator stress and initial effective confining pressure,

$$CSR = \frac{q_{cyc}}{2б'_{v0}} \quad (2.1)$$

Large number of cycles needed to reach the failure surface if the cyclic stress ratio is low whereas cyclic stress path reached the failure surface quicker when the cyclic stress ratio is comparably large (Zhou and Gong, 2001). They further discussed that accumulation of axial strain increased with increasing CSR, at the same time, once the CSR exceeds the threshold limit, increment of axial strain changed dramatically.

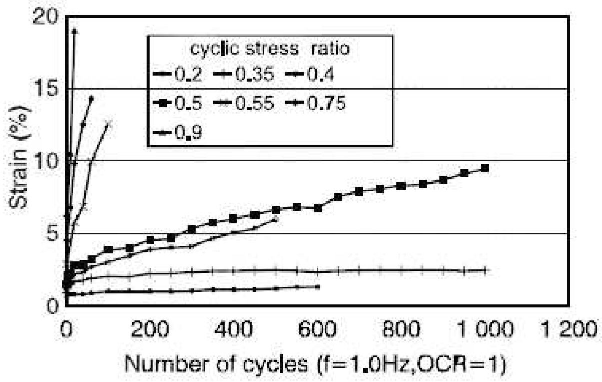


Fig 2-1: Effect of cyclic stress ratio on axial strain (adopted from Zhou and Gong 2001)

2.2 *Frequency (Hz)*

Rate of loading is importance of behaviour of stress strain characteristics on clay. Several researchers have studied about response of soil under various type of loading rate (Casacrande and Wilson, 1951, Lee and Focht Jr, 1976, Mortezaie and Vucetic, 2013, Richardson and Whitman, 1963, Thiers and Seed, 1969).

At constant water content, monotonic loading tests have been done with different rate of loadings (Casacrande and Wilson, 1951, Richardson and Whitman, 1963). Results showed that slow rate of loading reached the failure surface quicker since the generated excess pore water pressure was more compared to fast rate of loading. The hypothesis described by Theirs and Seed (1969) for this response is that soft soil creeps under sustained loading such as low rate frequency of loading.

However, Dynamic undrained strength of clay had no effect on frequency (Yasuhara, et al., 1982). In contrast, normally consolidated kaolinite clay having PI=28, low rate loading gave more pore water pressure than the higher rate loading (Mortezaie and Vucetic, 2013). Accumulation of axial strain and excess pore pressures were high when the cyclic time of loading was high. This phenomenon described that slow rate of loading affects more the resistance of clay skeleton by a fatigue phenomenon (Lefebvre and Leboeuf, 1987). At constant cyclic stress ratio, normally consolidated soil is degraded more with low frequency loading (Zhou and Gong, 2001).

Degradation Index (δ) of the soil stiffness is defined by degradation of soil secant modulus. The ratio of the secant modulus in the Nth cycle, (Es)N, divided by the secant modulus in the first cycle (Es)1 is given the degradation of the soil (Idriss, et al., 1976).

$$\delta = \frac{E_N}{E_1} \quad (2.2)$$

In addition, they found that rate of degradation (log δ) with number of cycles (log N) has the linear relationship.

$$t = -\frac{log\delta}{logN} \quad (2.3)$$

Where t is the degradation parameter

2.3 *Confining Pressure*

Soft soil at lower depth fails quickly compared to soil at deeper depth during moving train loads. Therefore it is necessary to evaluate the effect of confining pressure under cyclic loading. Empirical equation has been developed by Ishihara (1996) considering confining pressure (бc') for small strain dynamic shear modulus (Gmax).

$$G_{max} = A\frac{(B-e)^2}{1+e}(б'c)^c \quad (2.4)$$

Where A, B and C are laboratory measured values

It could be seen that maximum shear modulus is reducing with lowering confining pressure. Dynamic shear modulus is reduced more with low confining pressure compared to high confining pressure (Mortezaie and Vucetic, 2013).

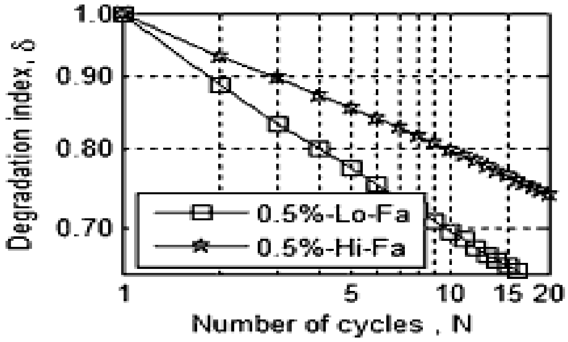
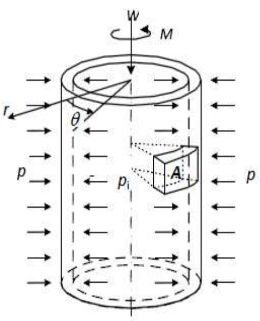


Fig. 2-2 Effect of the confining pressure on cyclic degradation (adopted from Mortezaie and Vucetic 2013)

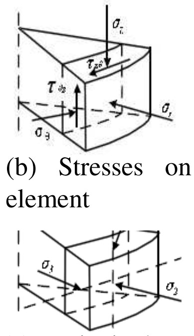
Lo, Hi and Fa are Low confining pressure, high confining pressure and fast loading respectively.

2.4 *Principal Stress Rotation (PSR)*

Moving loads in the ground produces essential feature in the soil. Most of the previous researchers, unfortunately, have not considered the rotation of the major principal stress direction which is important feature under cyclic loading. This effect will not be influenced significantly when the soil is isotropic. However loading on the ground is intrinsically anisotropic. Even if the soil is initially isotropic when the principal stress direction changes soil becomes anisotropy condition (Arthur, et al., 1981). Duringthe continuously changing the rotation angle, there was greater pore pressure generation when rotation angle changed from 0 to 45(Symes, et al., 1984).



(a) Loads on hollow cylinder



(b) Stresses on element

(c) Principal Stresses on element

With increasing rotation angle, Normalized undrained shear strength was reduced and pore pressure parameter was increased however effective friction angle had the peak value at 45 degree even though abnormal pattern was observed(Lin and Penumadu, 2005). The cyclic rotation of principal stress direction has given more permanent deformation with compared to conventional triaxial test results for constant cyclic stress ratio. In addition to that Critical dynamic stress ratio for principal stress rotation tests was less than the critical stress ratio in triaxial test results(Qian, et al.).

3 PHYSICAL PROPERTIES

3.1 *Plasticity Index (PI)*

The criteria for liquefiable cohesive soils were greater than 0.75 in Liquidity Limit (LL), less than 0.5daN/cm2, less than SPT 4 and greater than value of 4 in sensitivity which was called as "Chinese Criteria". However this criterion has been modified with Plasticity Index by Perlea(1999).

Degradation of NC marine clays under cyclic loading was high with low PI clays. This trend was same with both compression cyclic loading using triaxial apparatus and shear cyclic loading using shear apparatus in the wide range of Plasticity Index (Vucetic and Dobry, 1988). During the series of undrained cyclic strain controlled tests on silty clay, rate of increment in Degradation parameter (t) was increased more with low plasticity index soils (Lee and Sheu, 2007).

3.2 *Grain size*

In terms of volume, 60% of Gravel with Kaolin and 60% of Sand with Kaolin were subjected to strain controlled tests underundrained condition. They found the increment of pore water pressure was same in both mixtures at constant confining pressure (Jafari and Shafiee, 2004).In addition to that, degradation index (δ) also doesn't change significantly when the grain size is replaced in terms volume during cyclic triaxial test(Soltani-Jigheh and Soroush, 2010).

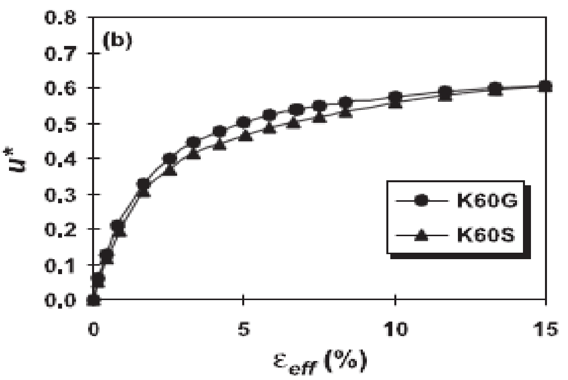


Fig 3-1: Effect of grain size on generation of pore water pressure (adopted from Soltani and Soroush 2010)

4 CONCLUSIONS

(a) Soft soil behaviour during high speed trains strongly depends on both mechanical and physical properties of soil.
(b) The generation of excess pore pressure and accumulation of axial strain is increased with increment of Cyclic Stress Ratio (CSR). Once the cyclic stress ratio exceeds the threshold limit, those output changes dramatically.
(c) Even though some results showed that frequency has no effect on cyclic loading, other few results indicated that excess pore pressure, axial strain and degradation of modulus affects more by low frequency loading.
(d) Under cyclic loading, soft soil degrades more with low confining pressure than high confining pressure.
(e) Principal stress direction changes with moving train loads. This behaviour increases the plastic deformation while it increases the modulus degradation of soil.
(f) Soft soil having low Plasticity Index degrades more compared to high plasticity soil with increasing number of cycles.
(g) Grain size of mixed soil does not affect the behaviour of soft soil in terms of excess pore water pressure and degradation of modulus.

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