CHAPTER- VII

DYNAMIC SHEAR MODULUS AND LIQUEFACTION ASSESSMENT OF HOMOGENEOUS AND STRATIFIED SOIL-ASH DEPOSIT

7.1 INTRODUCTION

Throughout the last two to three decades, there has been substantial research into determining the fundamental properties of waste materials. Numerous research (Pandian et al. 1998; Sridharan et al. 2001; Pandian 2004; Kim et al. 2005; Prakash and Sridharan 2009; Awang et al. 2012; Pant et al. 2019) examined all types of coal ash (fly ash, bottom ash, and pond ash) for geotechnical purposes. It has also been utilized by various authors to stabilize weak/soft soil (Prabakar et al. 2004; Senol et al. 2006; Kumar et al. 2007; Sharma et al. 2012). Low-strength waste materials were geosynthetically reinforced to increase their strength. On the other hand, some research on the dynamic characteristics of fly ash as a homogeneous material were examined under low and high shear strain conditions (Yu and Qin 1991; Kalinski and Wallace 2011; Yoshimoto et al. 2014; Chattaraj and Sengupta 2017; Ram and Mohanty 2021). Ishihara et al. (1980) investigated the cyclic behaviour of tailing materials and discovered that plastic tailings had a higher cyclic strength than non-plastic tailings. Several researchers (Fiegel and Kutter 1994; Amini and Sama 1999; Amini and Qi

2000; Konrad and Dubeau 2003; Amini and Chakravrty 2004) have conducted dynamic studies of layered silt-sand, sand-silt-gravel, silty sand, sand-silt; sand-gravel. Yoshimine and Koike (2005) employed the air pluviation method to stratify clean sand and discovered that the stratified layer had stronger liquefaction resistance than the uniform layer. Xiu et al. (2020) varied the thickness of a powdery layer injected in between sand and discovered a nonlinear relationship between thickness and cyclic stress.

Based on previous research, it can be concluded that the researchers' primary objective was to investigate the chemical/physical attributes and geotechnical performance of waste material (fly ash). Later on, several researchers became interested in the dynamic/seismic performance of waste materials (fly ash). There are few studies on the dynamic investigation of the layered soil-ash system. Because the use and disposal of fly ash resulted in the stratification of the composite system, it must be investigated before any recommendations for its field applications. As a result, in order to gain a better knowledge of fly ash, it should be studied not only in static conditions but also in dynamic conditions in homogenous and stratified forms while taking into account the existing soil layers. This will aid in the response analysis of all combinations, allowing its applicability to be expanded to seismically prone places as well.

The current work aims to measure the dynamic shear modulus of homogeneous and stratified soil-ash deposits. This was validated by executing 105 strain-controlled cycle triaxial tests. Cyclic (sinusoidal) loading with high shear strain amplitude was applied to cylindrical samples under the influence of varied loading frequencies, density, and effective confining pressure. The specimens were loaded repeatedly until liquefaction occurred. Also, the energy per unit volume necessary for liquefaction has been examined.

7.2 SIGNIFICANCE OF SHEAR MODULUS

Coal ash is typically dumped near thermal power plants, and due to geographical constraints, it is deposited in layers to a greater height. The standard slurry disposal approach covers around 40,000 hectares of land and requires 1040 million m^3 of water yearly (Mission energy 2020). These deposited heaps are haphazardly dumped, causing failure during the wet seasons and creating a hazardous environment for the livelihood. In India, 76 ash pond failures were observed between 2010 and 2020 (Shah and Narayan 2020). Furthermore, coal ash pollutes surface/subsurface water, air, and soil, causing a variety of health problems. Many of these coal ash-related concerns can be eliminated through the widespread use of coal ash in various applications. The ash must be investigated in static and dynamic loading settings for mass and long-term use. Furthermore, because ashes typically deposit in layers, these must be inspected for stratification. As a result, their interaction with the other layer must be investigated prior to the application. Also, the development of pore pressure is critical in predicting the failure of soil and ash deposits to liquefy. There is limited research published on the pore pressure response of soils, particularly stratified deposits. Hence, in this study, the dynamic shear modulus and liquefaction potential of homogeneous and stratified soil-ash deposit has been investigated.

7.3 METHODOLOGY AND EXPERIMENTAL PROGRAM

Soil liquefaction can be assessed using stress-based, strain-based, or energy-based techniques. The energy method is the only one that can be related to any of the other approaches (based on stress/strain). The basic assumption in the energy approach is that the amount of energy dissipation per unit volume, as indicated by the area of the hysteresis loop, directly relates to how much energy is required to change the volume or pore pressure of a system, whether it is undrained or drained condition (Nemat and Shakooh 1979). Nasser and Shakooh (1979) mathematically showed the link between the energy necessary to induce liquefaction in sand subjected to cyclic loading. This idea is based on the fact that when a sample is subjected to cyclic loading, particles rearrange, resulting in some energy dissipation, and a continuous decrease in the volume of void results in a progressive increase in pore water pressure. This generated pore pressure is responsible for the reduction in grain-to-grain contact, which eventually leads to liquefaction failure. Davis and Berrill (1982) were the first to use energy to evaluate the liquefaction potential of sand, and it was later extended by other researchers (Simcock et al. 1983; Berrill and Davis 1985; Law et al. 1990) to discover the association between the pore pressure and the area of hysteresis loop (energy dissipated). The energy method was used to analyze the liquefaction processes in numerous laboratory facilities such as torsional shear tests, cyclic triaxial tests, and so on (Figueroa et al. 1994). The stress-strain diagram of the hysteresis loop (Fig. 7.1), shows the area of strain energy dissipated and stored, and this dissipated energy until liquefaction may be computed using the equation presented below (Voznesensky and Nordal 1999).

$$\Delta W = \sum_{i=1}^{n-1} \frac{1}{2} (\sigma_i + \sigma_{i+1}) \ (\varepsilon_{i+1} - \varepsilon_i) \tag{7.1}$$

where, σ represents the deviator stress, ε represents the axial strain, and n signifies the number of cycles till liquefaction.

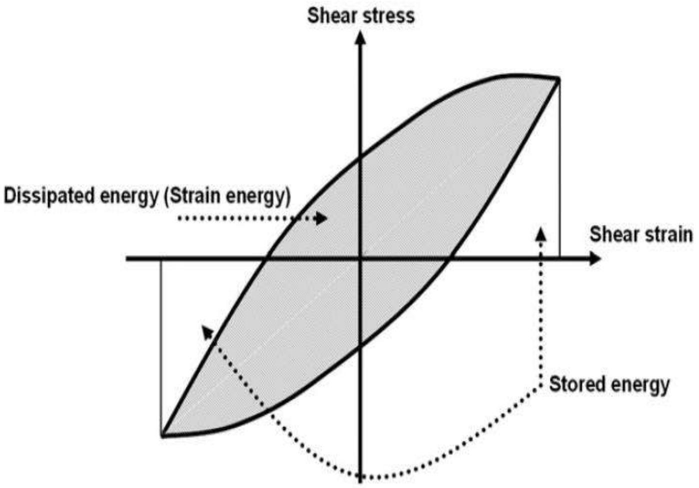


Fig. 7.1. Fundamental hysteresis loop of energy dissipation/stored mechanism (Green 2001).

The strain-controlled cyclic triaxial test was performed under consolidated undrained conditions with a shear strain of 0.3-1.5%. Furthermore, ASTM D-698 (2012) recommends that the fly ash should be densified at least 95-100% of its maximum dry density for the field applications. Hence, for the present study the relative compaction (RC) of 95, 97, 99% was incorporated. These dry densities were maintained for both the homogeneous and stratified soil-ash deposit. Most of the studies considered 1 Hz frequency of loading for high strain condition. Therefore, present soil samples were subjected to cyclic loading of 1 Hz frequency and to assess the rate of development of pore water pressure, samples were exposed to lower frequency of loading (0.5 & 0.3 Hz). To simulate the real field situations, the prepared samples were consolidated prior to shearing under the effective confining pressure of 100, 80, & 70 kPa. All these aforementioned influencing parameters were taken into consideration for fly ash, local soil and their combinations which results in total of 105 cyclic triaxial tests. The detailed experimental program of the present study has been tabulated in Table. 7.1.

Table 7.1. Laboratory experimental program of the cyclic triaxial test.

Type of Soil	Relative compaction	Frequency (f)	Effective confining pressure (σ')	Shear strain (γ)
	(%)	(Hz)	(kPa)	(%)
Fly ash Local soil Stratified soil	95	1	100	0.3, 0.6, 0.9, 1.2, & 1.5
	97	1	100	0.3, 0.6, 0.9, 1.2, & 1.5
	99	1	100	0.3, 0.6, 0.9, 1.2, & 1.5
	99	0.5	100	0.3, 0.6, 0.9, 1.2, & 1.5
	99	0.3	100	0.3, 0.6, 0.9, 1.2, & 1.5
	99	1	80	0.3, 0.6, 0.9, 1.2, & 1.5
	99	1	70	0.3, 0.6, 0.9, 1.2, & 1.5

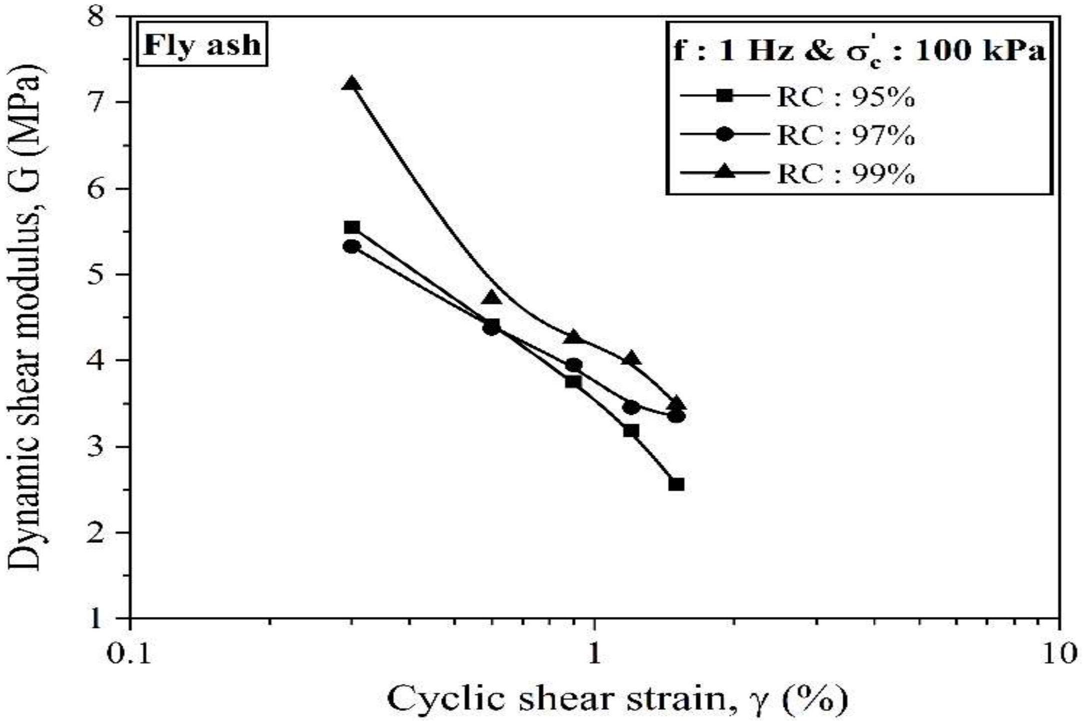
Total = 5×7×3 = 105

7.4 RESULTS AND DISCUSSION

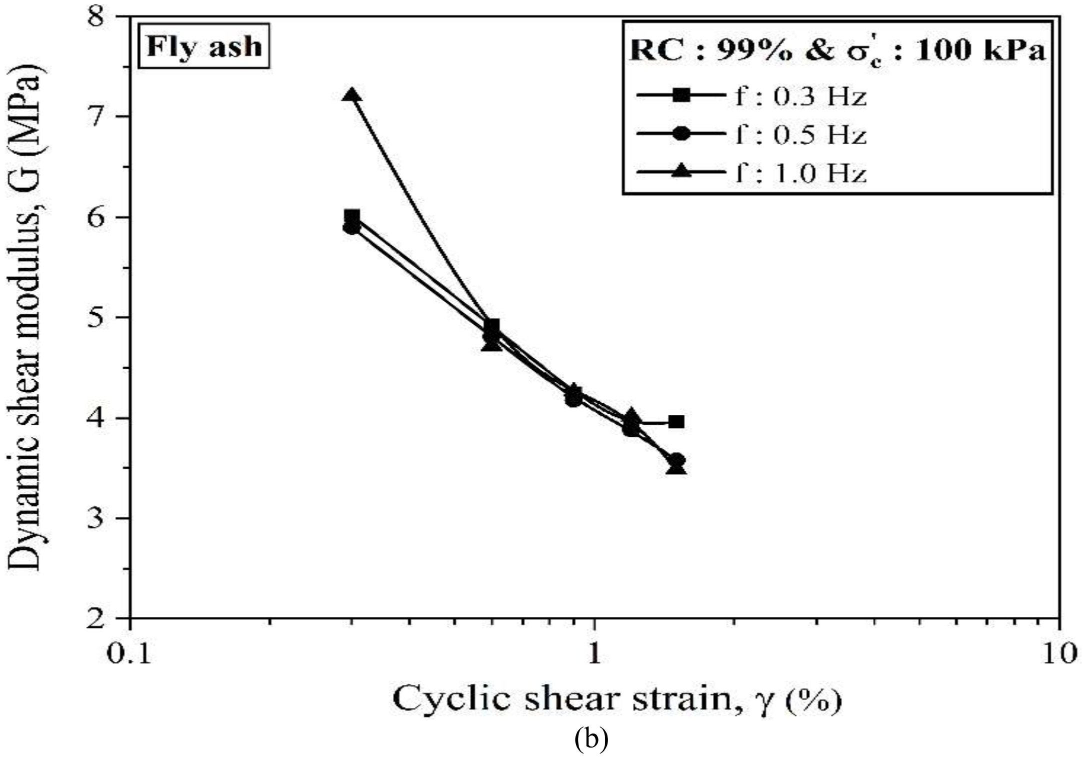
The dynamic properties of the fly ash, local soil, and stratified soil-ash combination has been discussed in details in this section. Here, the main parameters, relative compaction (RC), frequency of loading (f), effective confining pressure (σ'_c) are considered with varying cyclic shear strain. In addition, the evaluation of liquefaction potential using energy approach has also been addressed with all the aforementioned parameters. The experimental outcomes were divided into several subheadings which are explained in the subsequent sections.

7.4.1 Evaluation of Dynamic Shear Modulus of Homogeneous Soil and Fly Ash Specimens The response of dynamic shear modulus with cyclic shear strain for the homogeneous systems, namely fly ash and local soil, was briefly explained here. Fig. 7.2 depicts a graphical representation of the dynamic shear modulus of fly ash and local soil. The widely accepted liquefaction requirements for soil are 100% development of the excess pore pressure or an excess pore pressure ratio (r_u) value of one. However, it can also be connected with the percentage of shear strain, i.e., 6% double or single amplitude shear strain (Jiaer et al. 2004). The dynamic shear modulus decreases with the increase in cyclic shear strain. The higher relative compaction and effective confining pressure shows remarkable increase in the shear modulus in both the case of fly ash and local soil. The highly compacted specimen signifies higher degree of compactness that results in less availability of void ratio thus takes higher load than that of the lower RC specimens.

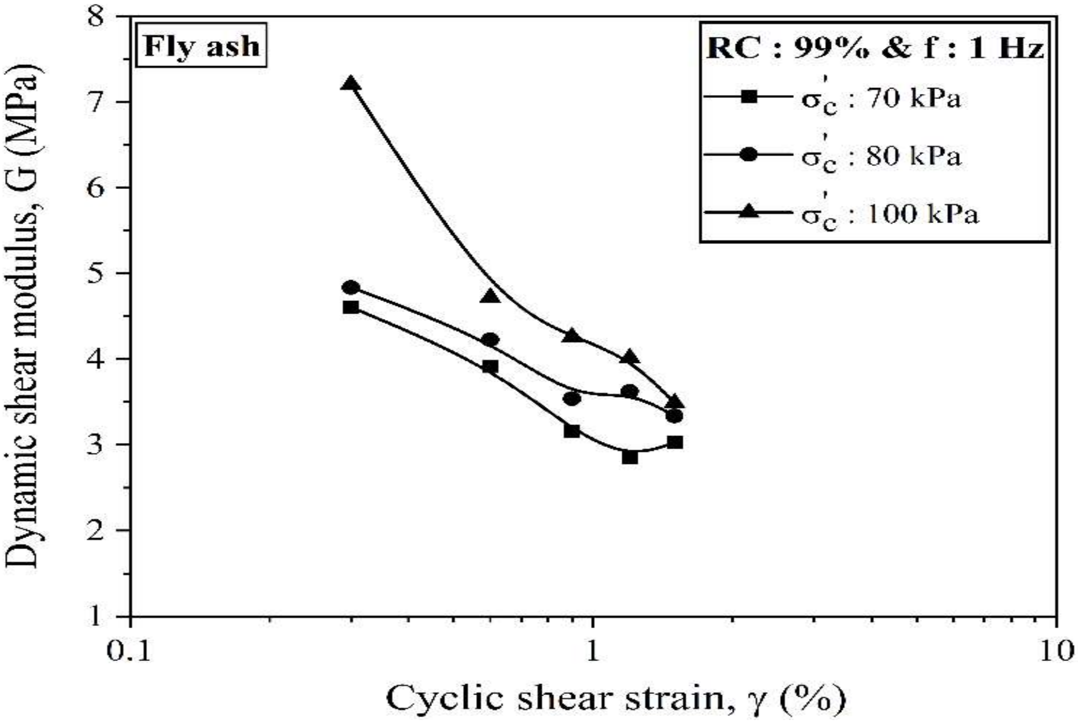
However, the local soil experiences a notable variation under the influence of frequency of loading whereas fly ash shows minimal variation with loading frequency. Zhu et al. (2021) conducted cyclic triaxial test on sand in both stress and strain control mode and found significant effect of loading frequency on liquefaction behaviour under saturated conditions. In contrast, various studies conducted on sand found negligible or minor variation of shear modulus with the influence of frequency (Townsend 1978; Ravishankar et al. 2005; Wilson and Saez 2017). Some of the researchers observed lower modulus for lower frequency (slower loading rate) (Lee and Fitton 1969; Lee and Focht 1975), whereas increase in modulus had been observed by various researchers for lower frequency range (Wang 1972; Wong et al. 1975; Mulilis 1975). From the above discussion this can be concluded that the cohesionless soil has insignificant effect of frequency on modulus reduction curve. On the other hand, cohesive soil has significant effect of frequency on shear modulus of soil.


Fly ash
f : 1 Hz & σ'_c : 100 kPa
RC : 95%
RC : 97%
RC : 99%
Dynamic shear modulus, G (MPa)
Cyclic shear strain, γ (%)
1
2
3
4
5
6
7
8
0.1
1
10

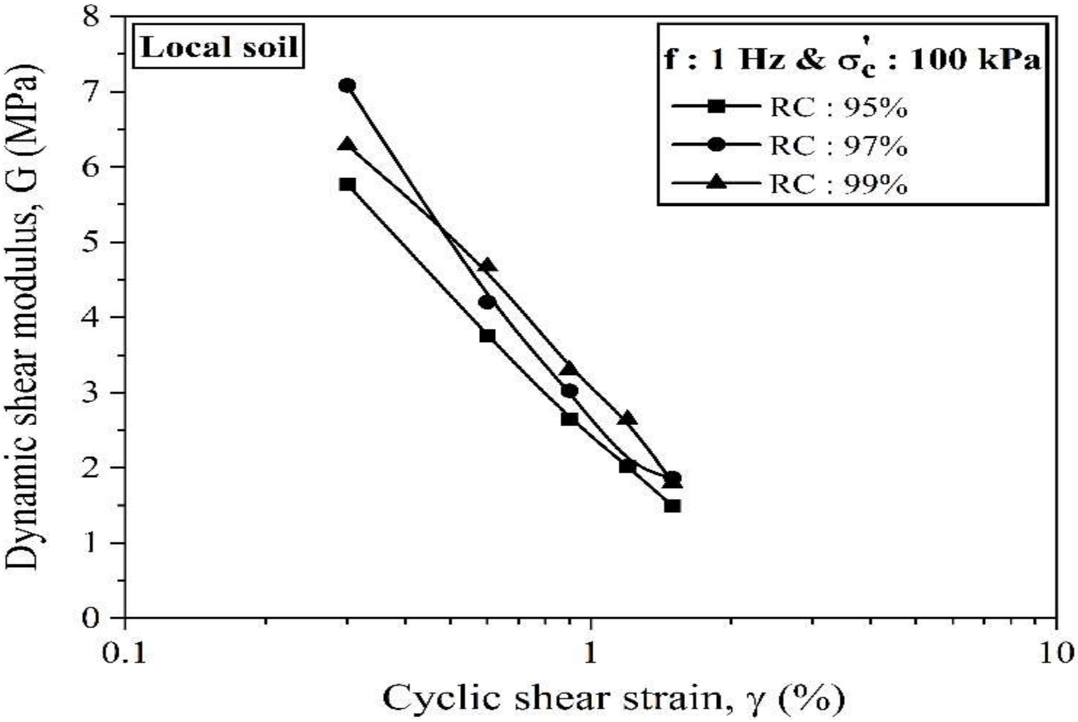
(a)


Fly ash
RC : 99% & σ'_c : 100 kPa
f : 0.3 Hz
f : 0.5 Hz
f : 1.0 Hz
Dynamic shear modulus, G (MPa)
Cyclic shear strain, γ (%)
2
3
4
5
6
7
8
0.1
1
10

(b)


Fly ash
RC : 99% & f : 1 Hz
σ'_c : 70 kPa
σ'_c : 80 kPa
σ'_c : 100 kPa
Dynamic shear modulus, G (MPa)
Cyclic shear strain, γ (%)
1
2
3
4
5
6
7
8
0.1
1
10

(c)


Local soil
f : 1 Hz & σ'_c : 100 kPa
RC : 95%
RC : 97%
RC : 99%
Dynamic shear modulus, G (MPa)
Cyclic shear strain, γ (%)
0
1
2
3
4
5
6
7
8
0.1
1
10

(d)

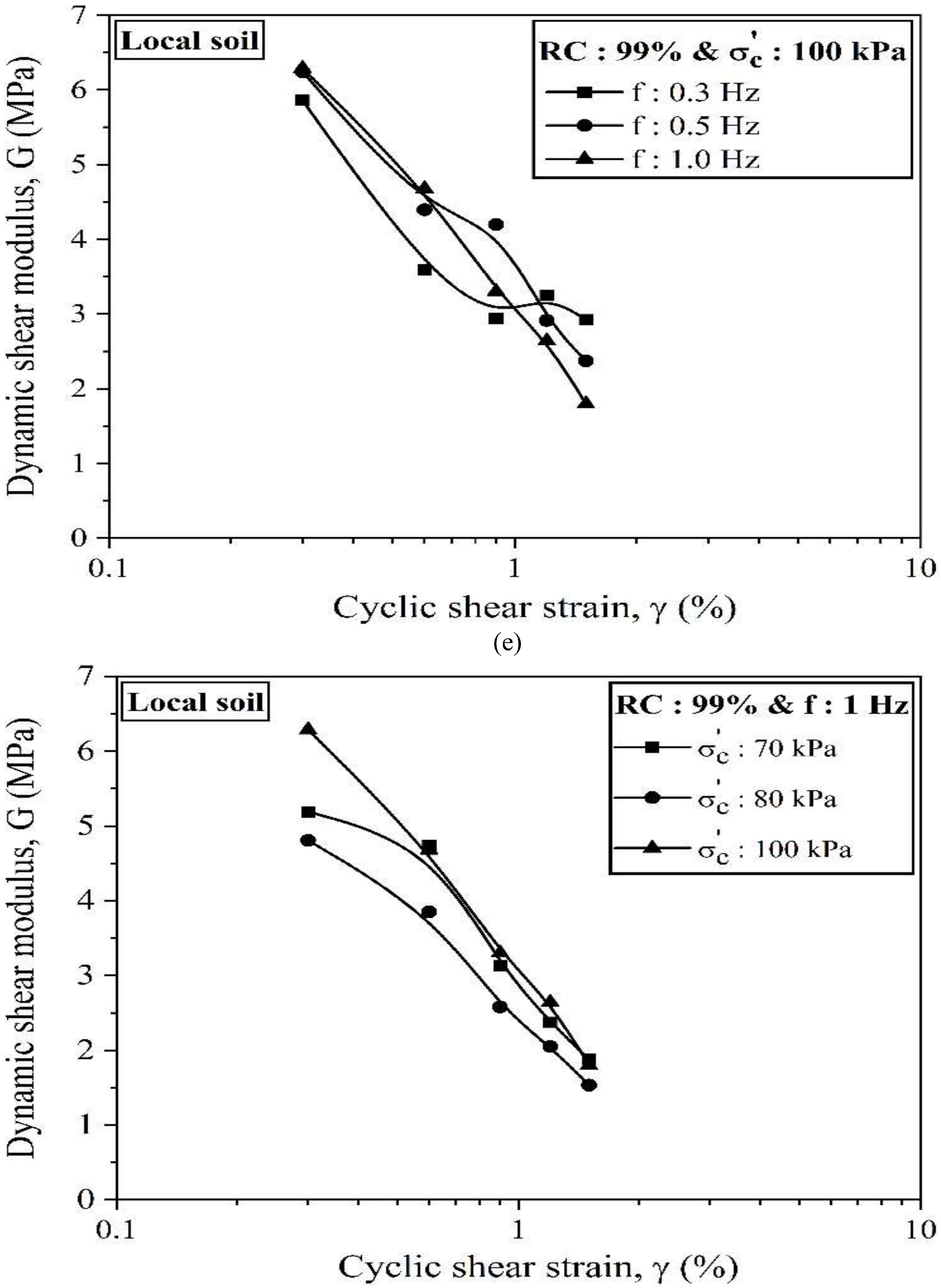
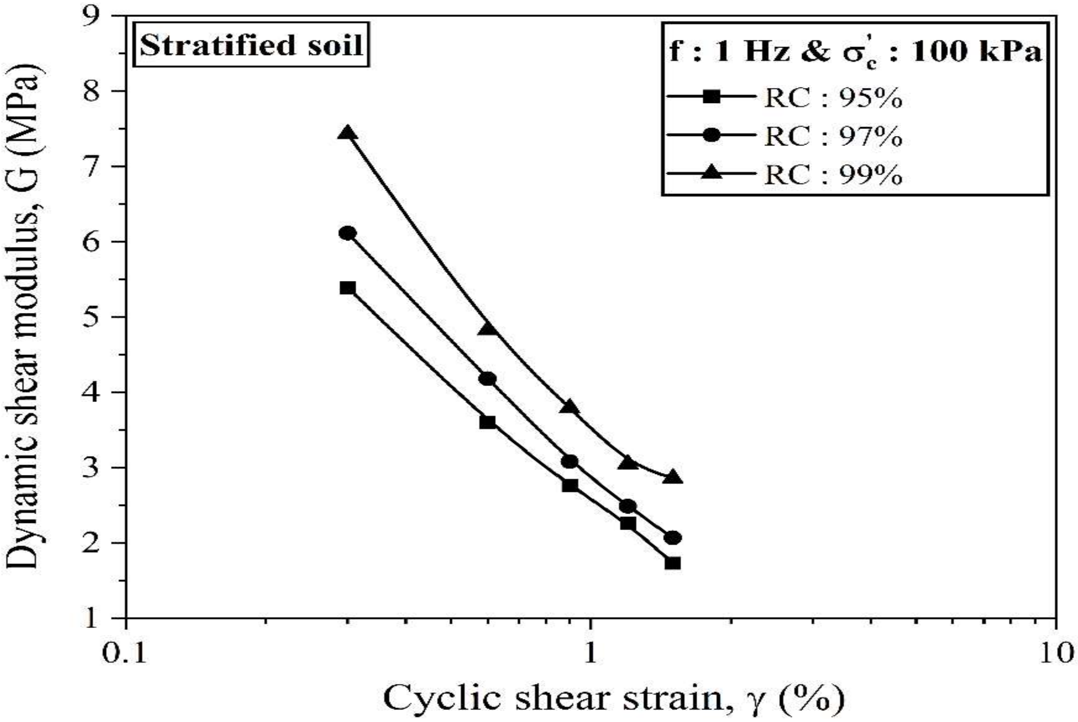


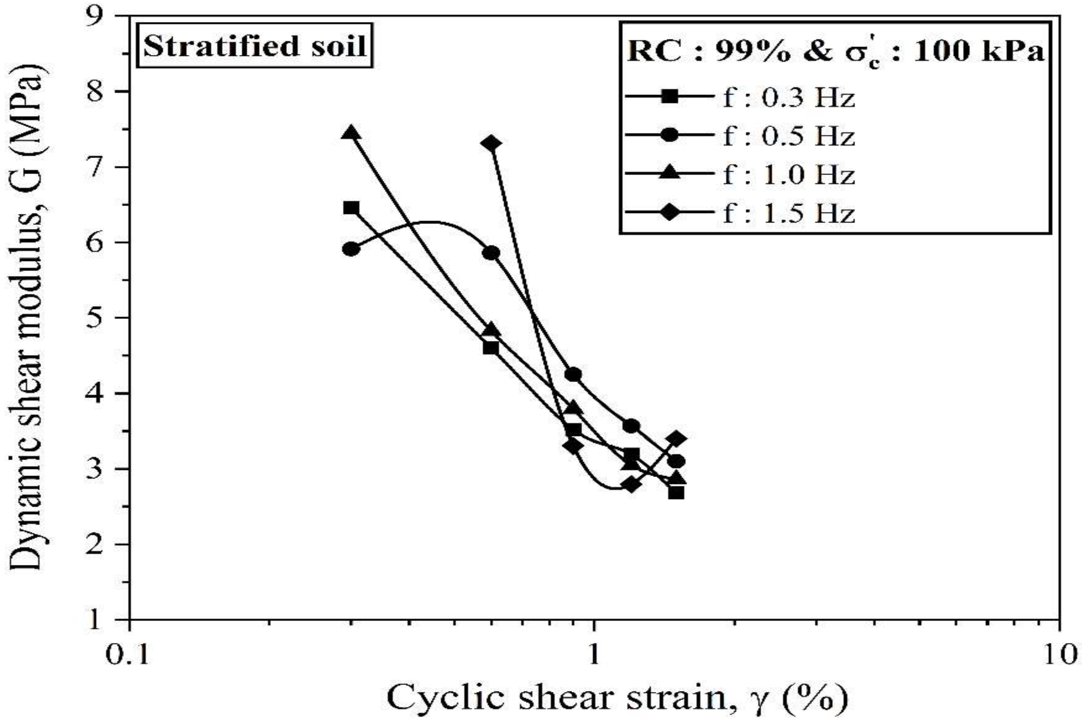
Fig. 7.2. Dynamic shear modulus illustration of fly ash and local soil considering each influencing parameter.

7.4.2 Evaluation of Dynamic Shear Modulus of Stratified Soil-Ash Deposit

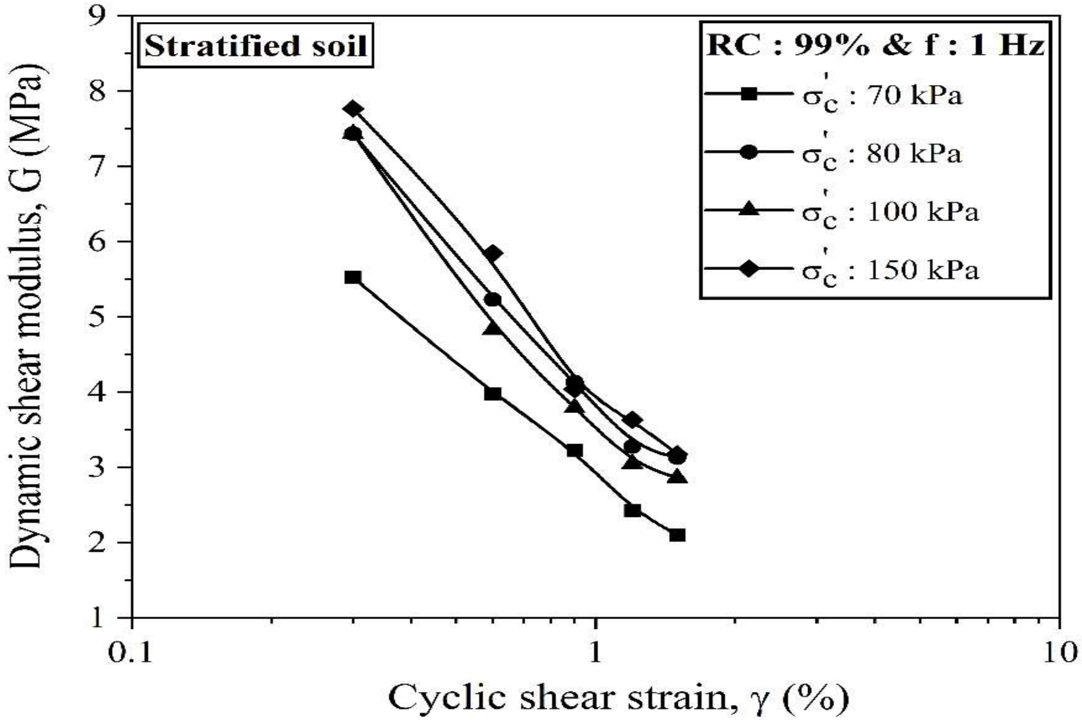
The stratified soil-ash deposit subjected to cyclic loading under the undrained condition were examined to check its performance during seismic activities. The shear modulus versus shear strain response of the stratified soil-ash deposit under the influence of density, frequency and effective confining pressure has been demonstrated in Fig. 7.3. The effect of relative compaction and effective confining pressure on shear modulus of stratified soil-ash deposit was found to be same as that of the uniform soil, i.e., increases with the increase in relative compaction and confining pressure. However, frequency effect of stratified soil-ash deposit on shear modulus were similar with the response of local soil. This must be due to the low permeability behaviour of the local soil than that of the fly ash. The stratified soil-ash system shows higher shear modulus than that of the fly ash and local soil for shear strain of 0.3% & 0.6%. After 0.6% shear strain (>0.6%), the shear modulus of stratified soil-ash system falls in between fly ash and local soil. The liquefaction strength of stratified soil-ash system arrangements is found to be high for low strain condition and gradually shifted towards strength of the uniform soil deposit. Konrad and Dubeau (2003) examined the cyclic behaviour of the stratified sand-silt sample and found decrement in the cyclic strength of the stratified sample as compared to the uniform sample due to the generation of differential pore pressure. Amini and Sama (1999) and Amini et al. (2000) considered stratified silty sand and sand-silt-gravel composites, and concluded that the resistance to liquefaction of stratified and the uniform soil arrangements are same irrespective of the sample preparation technique (moist tamping and sedimentation). Yoshimine and Koike (2005) prepared the stratified specimen with the segregated particles of clean sand, the results depicted that the strength to resist liquefaction was high for stratified soil than that of the uniform soil. Hence, this can be concluded that the present stratified soil-ash deposit has good cyclic strength and can be recommended for the application with shear strain between low to medium range from the safety perspective of the superstructure resting on it.



(a)



(b)

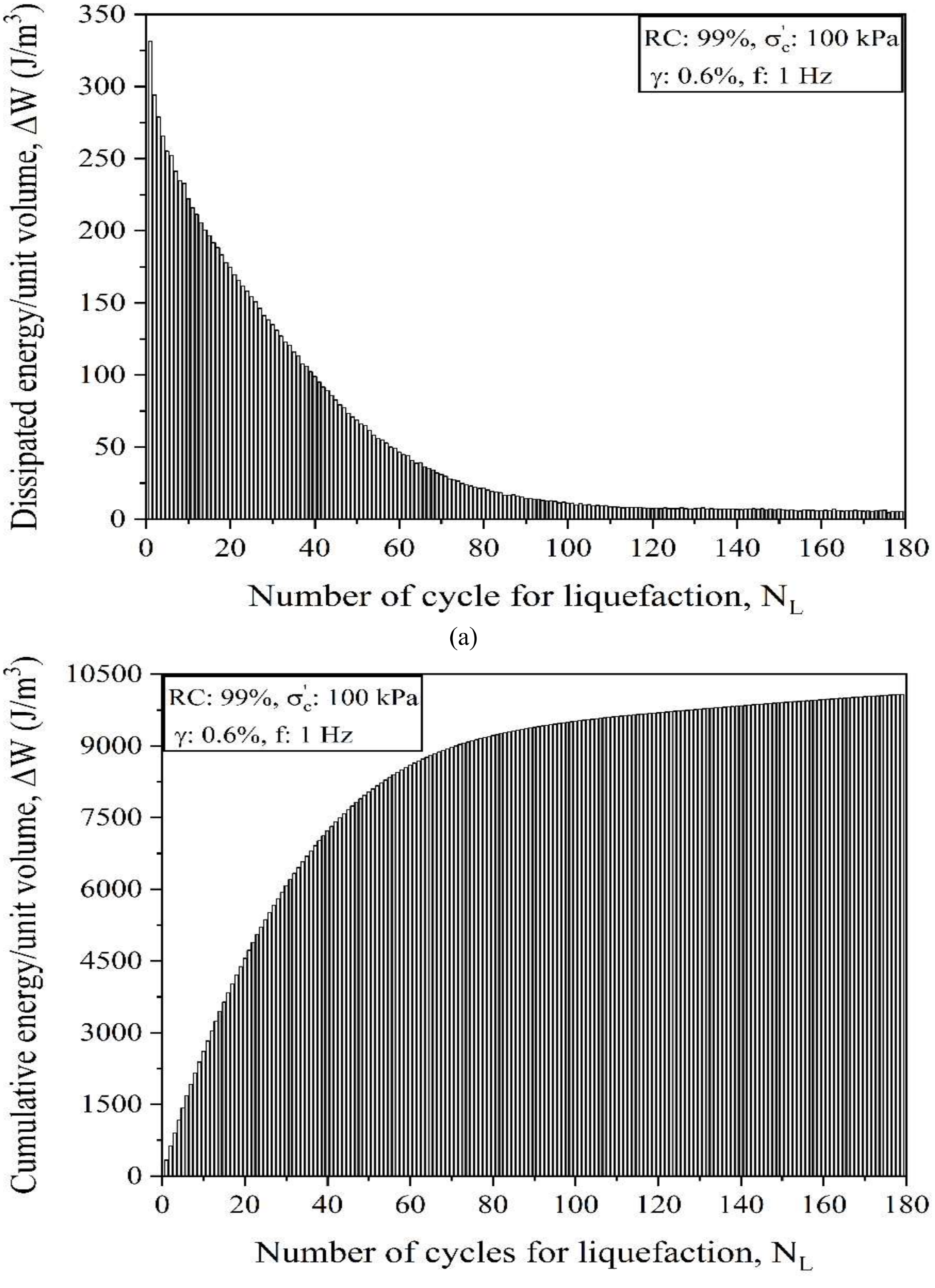


(c)

Fig. 7.3. Graphical representation of dynamic shear modulus of the stratified soil-ash deposit considering each influencing parameter.

7.4.3 Evaluation of Liquefaction Potential by Energy Approach

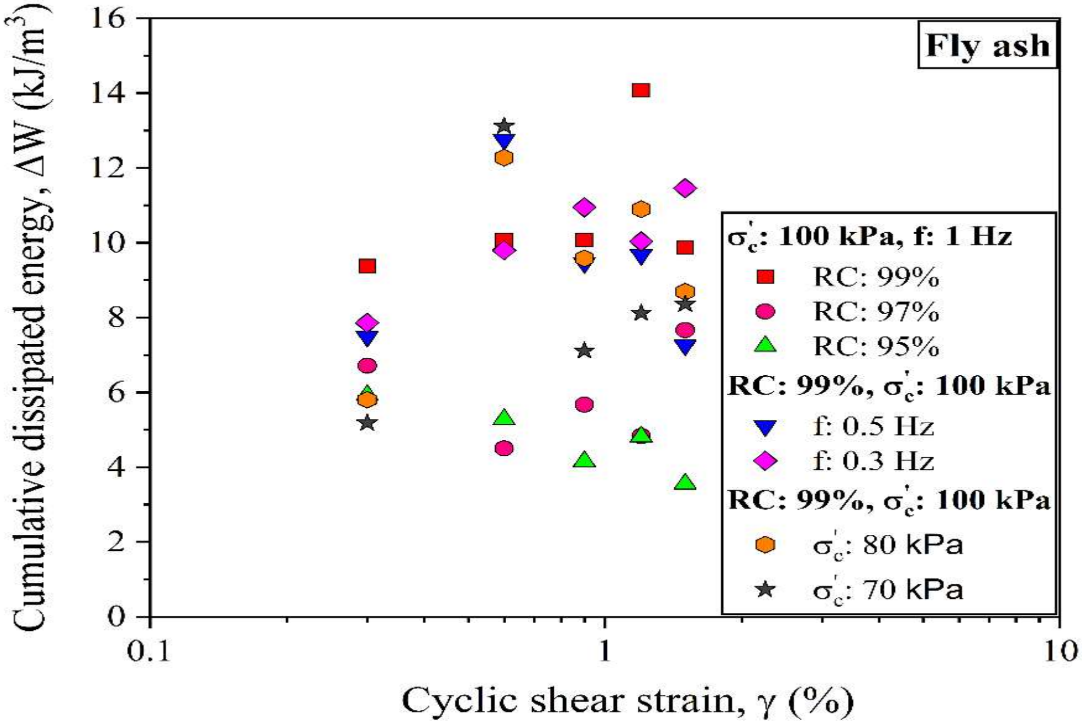
The concept of energy in liquefaction analysis of granular materials was initially started in the year 1979. This approach provides a realistic scenario for the comparison of dissipated energy with the energy released during the seismic events. The dissipated energy can be directly evaluated from the area enclosed by the hysteresis loop developed during the cyclic loading (Fig. 7.1). During initial cycle of cyclic loading, the area of hysteresis loop will be large due to the low pore pressure. And as the pore pressure increases, the load resistance of sample gets reduced that ultimately minimize the area of loop to a flatter line till liquefaction. The typical representation of the energy and cumulative energy dissipation per unit volume with the number of cycle (liquefaction) for fly ash has been shown in Fig. 7.4. The Fig. 7.4(a) depicts the degradation of the energy because of the reduction in the size of hysteresis loop with the increase in cycle. Whereas the total energy required for the failure of sample has been plotted in Fig. 7.4(b) after adding cumulative energy till the last cycle. In addition, the variation of total energy with varying shear strain under the influence of density, loading frequency, and effective confining pressure as variable parameters were investigated. The distribution of dissipated energy with different independent variables for homogeneous (fly ash and local soil) and stratified soil-ash deposit has been illustrated in Fig. 7.5. The local soil exhibits high energy per unit volume followed by stratified soil-ash and fly ash. This happens because of the cohesive nature of the local soil that causes resistance to rapid development of pore pressure. The relative compaction variation shows higher energy for soil compacted in higher degree of compaction in all the cases. Similarly, with the increase in effective confining pressure the pore water escapes out during consolidation that results in gradual increase in pore pressure during shearing. Thus, under high effective confining pressure, higher energy requirement has been observed. The frequency of loading was varied between 0.3 Hz to 1 Hz and indicates high required energy for higher frequency of cyclic loading. The estimated energy is directly dependent on the area of the enclosed loop and for higher loading frequency the shear resistance noticed was high, which results in large area of loop as compared with the lower frequencies. The energy observed in the case of fly ash for lower frequency range was approximately same. All the considered soil shows significant variation of energy with the change in cyclic shear strain. From Fig. 7.5, this can be observed that initially the energy increases and reaches to a peak then decreases with shear strain. Similar trend of energy variation has been noticed by Kumar et al. (2017) in the case of damping ratio. The peak energy varies between 0.6 to 1% of shear strain for both the case of homogeneous and stratified soil-ash deposit. In contrast, Figueroa et al. (1994) has observed negligible variation of energy with strain and concluded that the energy per unit volume for liquefaction is independent of the shear strain for sand. From the present investigation, this can be summarized that the energy dissipation is dependent on all the parameters discussed above, but it is independent of the number of cycles needed for liquefaction. After analyzing the past earthquake case histories, a relationship between energy and N-values of standard penetration test were developed by Green (2001). As per this relation, the range of energy required for liquefaction is around 0.03 – 0.192 kJ/m^3 for the soil having N value between 5 – 15 blows per feet and effective confining pressure of 100 kPa. Densification of sand is necessary criteria for better liquefaction resistance and the energy required for fine grained soil (semi pervious) & clay deposits resting above ground water table is fall in the range of 250-350 kJ/m^3 energy (Green and Mitchell 2004).



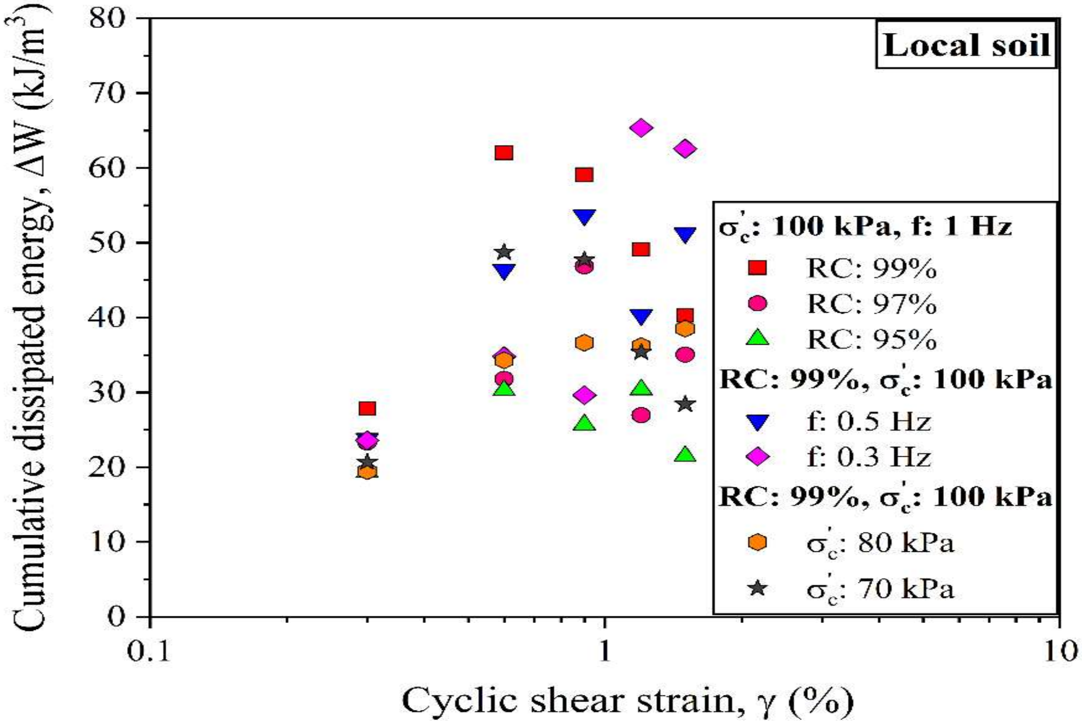
(a)

(b)

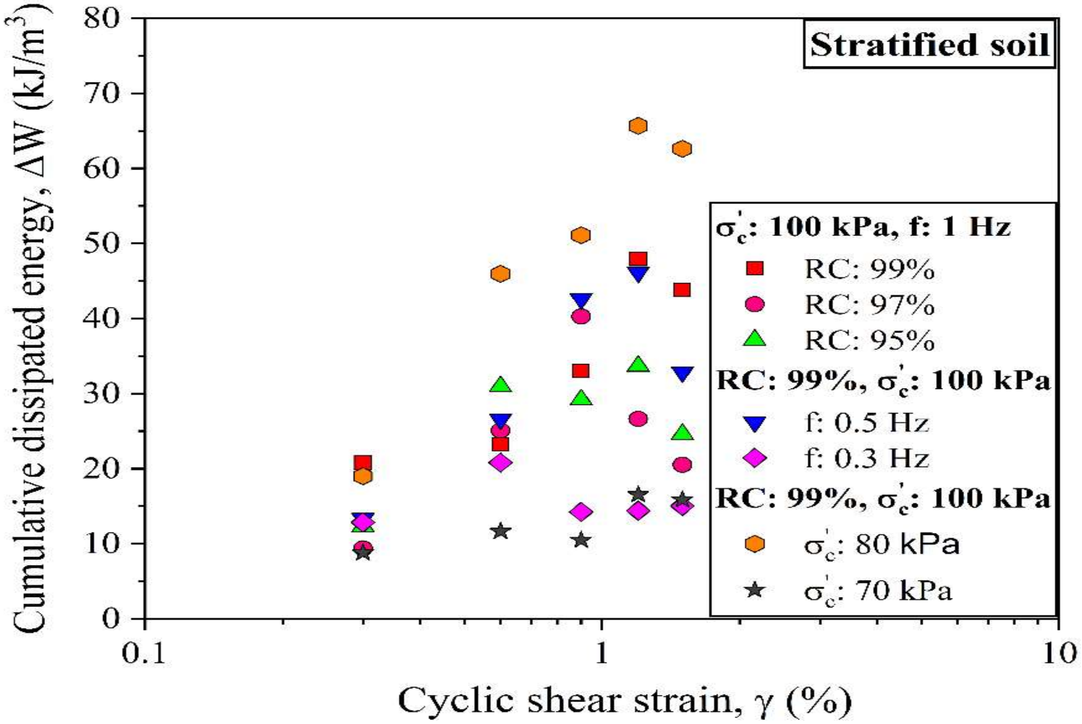
Fig. 7.4. Typical plot of the variation of dissipated energy and its cumulative energy with number of cycles for liquefaction in the case of fly ash.


Fly ash
Cumulative dissipated energy, ΔW (kJ/m³)
0
2
4
6
8
10
12
14
16
0.1
1
10
Cyclic shear strain, γ (%)
σ'c: 100 kPa, f: 1 Hz
RC: 99%
RC: 97%
RC: 95%
RC: 99%, σ'c: 100 kPa
f: 0.5 Hz
f: 0.3 Hz
RC: 99%, σ'c: 100 kPa
σ'c: 80 kPa
σ'c: 70 kPa

(a)


Local soil
Cumulative dissipated energy, ΔW (kJ/m³)
0
10
20
30
40
50
60
70
80
0.1
1
10
Cyclic shear strain, γ (%)
σ'c: 100 kPa, f: 1 Hz
RC: 99%
RC: 97%
RC: 95%
RC: 99%, σ'c: 100 kPa
f: 0.5 Hz
f: 0.3 Hz
RC: 99%, σ'c: 100 kPa
σ'c: 80 kPa
σ'c: 70 kPa

(b)



(c)

Fig. 7.5. Variation of cumulative dissipated energy of (a) fly ash, (b) local soil, and (c) stratified soil-ash deposit with cyclic shear strain.

7.4.4 Assessment of Strain Energy Correlation with Independent Parameters

The strain energy required till the failure of the specimen (sand or pond ash) under undrained conditions in laboratory were investigated by various researchers and expressed in simplest form of equations (Figueroa et al. 1994; Baziar and Jafarian 2007; Reddy et al. 2020). These equations help to approximately determine the energy required for the failure of the samples. Considering the past works, the present study also attempted to establish relationship between dissipated energy and other incorporated independent parameters for a complex system of fly ash, local soil and stratified soil-ash deposit. The expression for homogeneous and stratified soil-ash deposit are presented below (Eqn. 7.2-Fly ash, Eqn. 7.3-Local soil, Eqn. 7.4-Stratified soil-ash) by performing regression analysis considering RC, σ'_c, & γ as the independent parameters. In the same way, along with the above discussed three parameters, the frequency of loading was also incorporated to develop the expression including more variables, so that it can be widely applicable. The Eqn. 7.5 – 7.7 describe the four parameter expressions for the fly ash, local soil and stratified soil-ash deposit respectively are presented below:

$$\mathrm{Log}_{10}(\Delta W) = -9.905 + 0.107RC + 0.0026\sigma'_c + 0.049\gamma \quad (R^2=0.78) \tag{7.2}$$

$$\mathrm{Log}_{10}(\Delta W) = -5.742 + 0.065RC + 0.0065\sigma'_c + 0.200\gamma \quad (R^2=0.72) \tag{7.3}$$

$$\mathrm{Log}_{10}(\Delta W) = -2.234 + 0.022RC + 0.0106\sigma'_c + 0.572\gamma \quad (R^2=0.74) \tag{7.4}$$

$$\mathrm{Log}_{10}(\Delta W) = -10.459 + 0.110RC + 0.0039\sigma'_c + 0.069\gamma + 0.027f \quad (R^2=0.82) \tag{7.5}$$

$$\mathrm{Log}_{10}(\Delta W) = -4.998 + 0.058RC + 0.0061\sigma'_c + 0.237\gamma + 0.021f \quad (R^2=0.77) \tag{7.6}$$

$$\mathrm{Log}_{10}(\Delta W) = -4.908 + 0.0437RC + 0.0143\sigma'_c + 0.196\gamma + 0.507f \quad (R^2=0.77) \tag{7.7}$$

where, ΔW: dissipated energy per unit volume (kJ/m^3), RC: relative compaction required to maintain the density of sample (%), σ'_c: effective confining pressure during shearing and consolidation (kPa), γ: magnitude of shear strain subjected during cyclic loading (%), f: frequency of applied loading, R^2: coefficient of determination.

The coefficient of determinations of three independent variable equations were increased by 4-6% after including frequency as fourth independent variable. Hence, it is better to consider all the possible variables while deriving the expression because wide varieties of testing conditions can be fitted in a single equation for a particular type of soil. Similar kind of increment of 5% in R^2 has also been observed by Figueroa et al. (1994) with the increase in the independent variable from two to three. The limitation of these equation is that it cannot be applied to all types of soil. This was confirmed by fitting the models from Figueroa et al. (1994) and Reddy et al. (2020) with the available data set, which revealed greater magnitudes of energy of about 3-6 times for fly ash and 2-3 times for local soil/stratified soil-ash deposit. Therefore, a substantial amount of strain energy data from various types of soil should be considered for the regression analysis in order to establish a universal model. Considering the complexity of the fly ash, local soil and stratified soil-ash deposit, it is significantly important to perform energy estimation of waste materials so that their performance can be predicted in the seismic prone areas prior to the application.

7.4.5 Comparison of Present Study Results with Past Literature

The comparison of present study results has been done with the past studies in order to identify the similarity of the present evaluated shear modulus data with variety of soils. The individual diagrammatical illustration of density, loading frequency, and effective confining pressure effect has been done to establish similarity between the present and past studies (Fig. 7.6, 7.7, and 7.8). The comparison has been performed by varying one parameter and keeping constant other parameters. For example, in density effect, the density is variable whereas the other factors such as frequency and effective confining pressure are kept constant at 1 Hz & 100 kPa respectively. The present experimental data are compared with the fly ash, pond ash, lightweight expanded clay aggregates, and sand collected from various parts of India (Chattaraj and Sengupta 2017; Ravishankar et al. 2005; Das and Chakrabortty 2022; Kumar et al. 2017; Reddy et al. 2020; Dammala et al. 2017 & 2019; Jaya et al. 2012; Gao et al. 2021). The data covered wide range of cyclic shear strain which has been determined using Bender element

(<0.001), Resonant column (<0.01), and Cyclic triaxial (>0.01) tests (Ingale et al. 2017; Wong et al. 1975). From the above figures, this can be confirmed that the behaviour of shear modulus with shear strain for different variables is same irrespective of the range of strain (low to high). In the case of RC/RD effect, similar kind of observation has been witnessed for the past studies as well and found comparable shear modulus of sand with the present considered materials in the current strain range. The effective confining pressure effect of the present soil has also shown a good correlation with the past studies and observed very close magnitude of shear modulus of Brahmaputra and Chennai sand as compared with the present study (Fig. 7.8). These sands are mostly content fine sand and falls in the category of uniformly/poorly graded sand (SP) as per the Unified Soil Classification System. In the same way, the alluvial sand and Sabarmati sand has also presented similar modulus reduction behaviour in comparison with the present materials in Fig. 7.7. However, pond ash shows little higher magnitude due to the presence of equal proportion of silt and sand size particles. The local soil and stratified soil-ash deposit experiences remarkable variation of shear modulus with the change in frequency whereas fly ash got almost similar shear modulus irrespective of the change in frequency. Negligible effect of loading frequency has been noticed by several researchers specially in the case of cohesionless soil (Townsend 1978; Ravishankar et al. 2005; Das and Chakrabortty 2021).

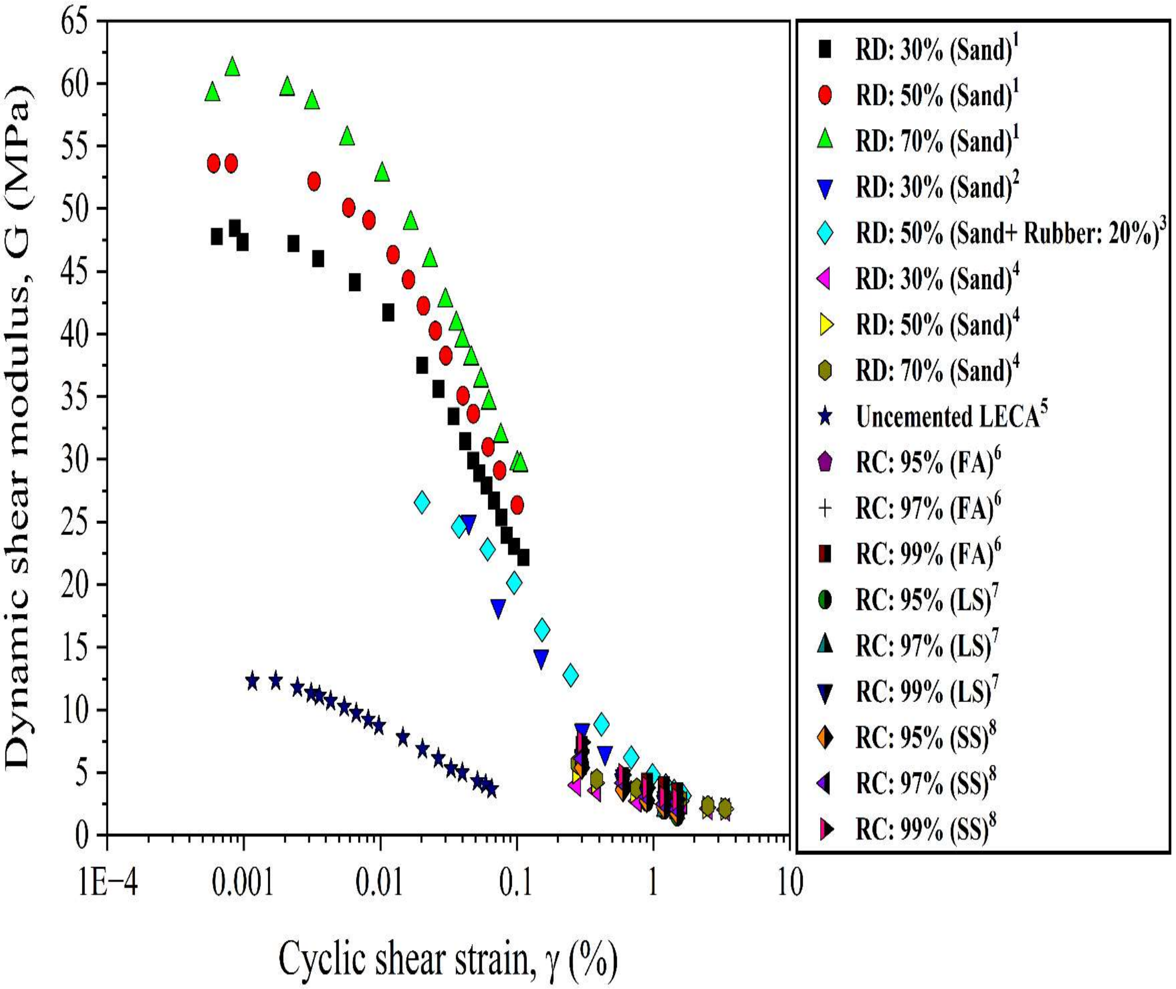


Fig. 7.6. Comparison of the shear modulus of various soil prepared under different densities. ([1]: Dammala et al. 2017, [2]: Kumar et al. 2017, [3]: Li et al. 2020, [4]: Ravishankar et al. 2005, [5]: Gao et al. 2021 (Lightweight expanded clay aggregate), [6,7,&8]: Fly ash, Local soil, and Stratified soil (present study))

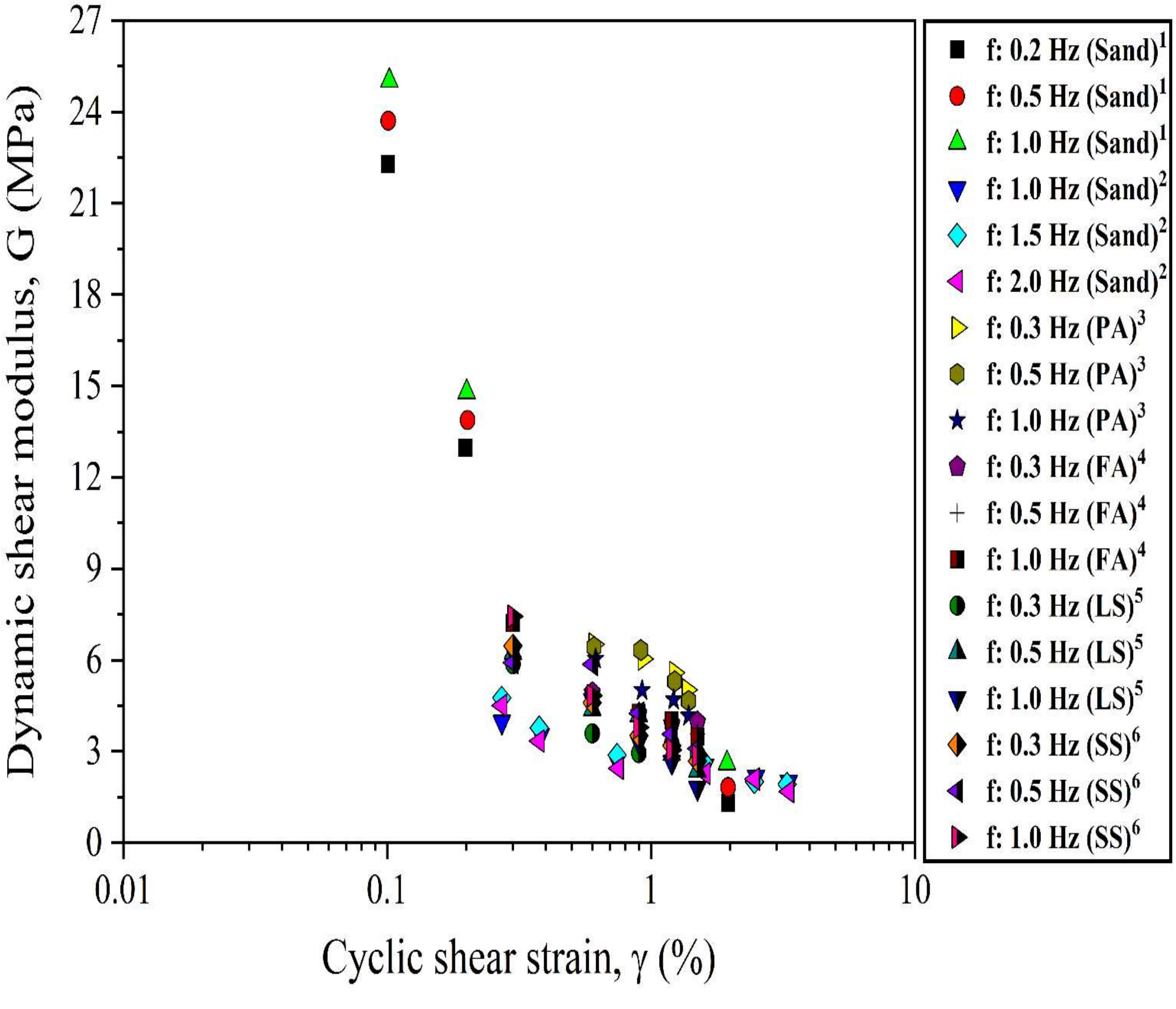


Fig. 7.7. Comparison of the shear modulus of various soil loaded under different frequencies of loading. ([1]: Das and Chakraborty 2022, [2]: Ravishankar et al. 2005, [3]: Reddy et al. 2021, [4,5,&6]: Fly ash, Local soil, and Stratified soil (present study))

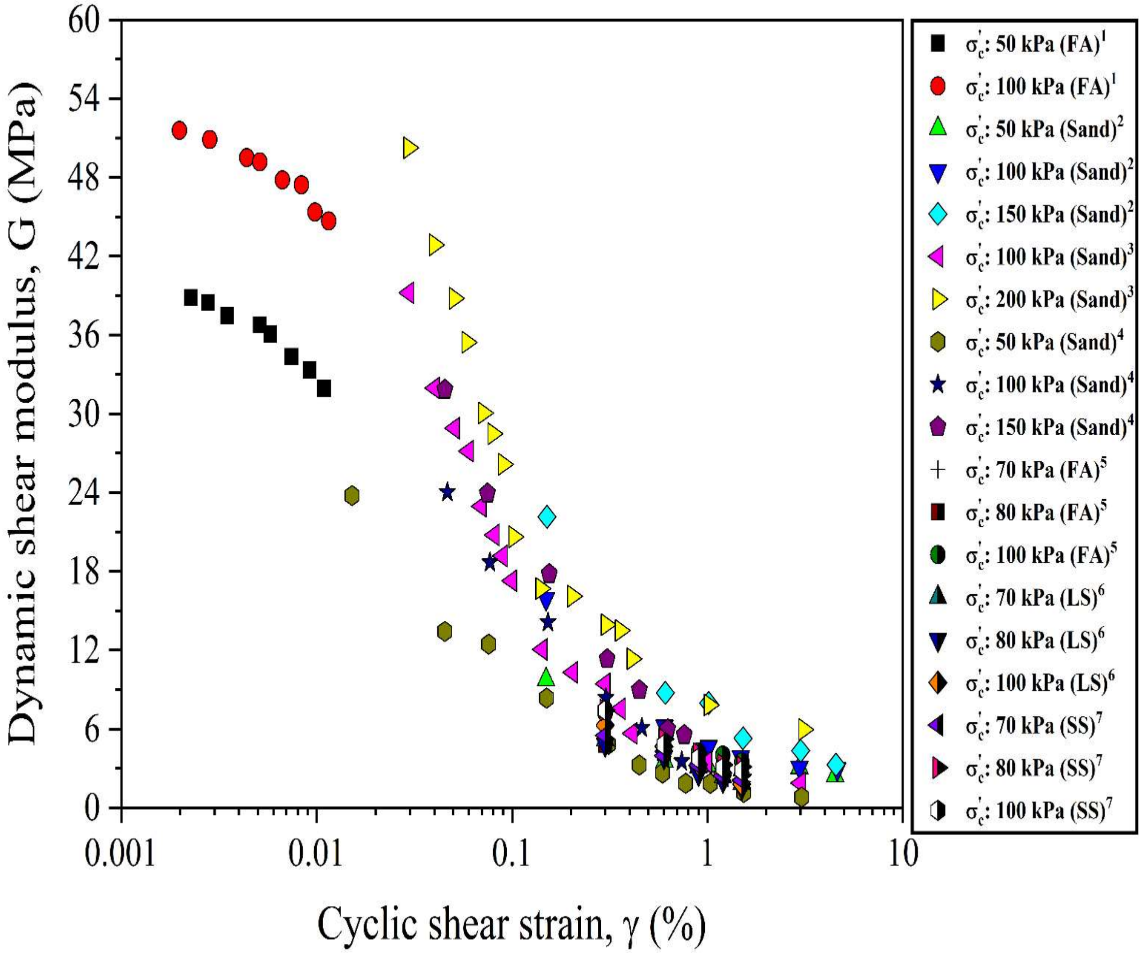


Fig. 7.8. Comparison of the shear modulus of various soil consolidated under different effective confining pressure. ([1]: Chattaraj and Sengupta 2017, [2]: Dammala et al. 2019, [3]: Jaya et al. 2012, [4]: Kumar et al. 2017, [5,6,&7]: Fly ash, Local soil, and Stratified soil (present study))

7.5 SUMMARY

The consolidated undrained cyclic triaxial test were performed in order to determine the dynamic shear modulus under the influence of relative compaction, effective confining pressure, and loading frequency. After evaluating the outcomes of the experimental program following conclusions can be drawn:

The study investigated the behavior of the stratified soil-ash systems, i.e., fly ash, and local soil in terms of dynamic shear modulus, the energy required for liquefaction, loading frequency effects, and cyclic strength. The results indicate that the stratified soil-ash system exhibits higher dynamic shear modulus as compared to the fly ash and local soil for a shear strain of 0.3% and 0.6%. Beyond 0.6% shear strain, the shear modulus of the stratified soil-ash system becomes comparable to the homogeneous system. In terms of liquefaction susceptibility, the local soil requires the highest energy per unit volume for the liquefaction, followed by the stratified soil-ash system and fly ash. The energy required for liquefaction is found to be depended on all the considered parameters and is independent of the number of loading cycles needed to induce liquefaction. However, the sample subjected to various loading frequencies has a significant influence on the local soil and stratified soil-ash deposits, affecting their behavior. In contrast, fly ash is least affected by the frequency of loading. The shear modulus versus shear strain relationship of the studied materials is compared with different materials but found comparable to sand with higher fine content. Notably, the stratified soil-ash deposit shows significant improvement in the cyclic strength. This makes it a suitable choice for the applications in seismic areas where shear strain is limited to the medium strain range. Overall, these findings provide a valuable insight into the dynamic behavior and liquefaction resistance of the studied materials, highlighting the potential advantages of the stratified soil-ash deposits in enhancing the cyclic strength and supporting their recommendation for medium seismic prone regions.