Strength parameters of asphalt concrete used in core zone of earth dams

Les Paramètres de Force de Béton bitumineux utilisé dans la Zone de Base de Digues de Terre

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ABSTRACT

Strength parameters of asphalt concrete used in earth fill dams' core were studied by conducting cyclic and monotonic triaxial tests on asphalt concrete samples. Results obtained from more than 120 cyclic tests showed that asphalt concrete behaves properly under cyclic loading and specimens stay intact after applying 5000 cycles. Results of monotonic and post-cyclic loading proved that strength parameters of asphalt concrete samples does not change significantly after being subjected to seismic loads.

RÉSUMÉ

Les paramètres de force de béton bitumineux utilisé dans la terre se remplissent le cœur de digues a été étudié en accomplissant des épreuves de triaxial cycliques et mono toniques sur les échantillons de béton bitumineux. Les résultats obtenus de plus de 120 épreuves cycliques ont montré que le béton bitumineux se comporte correctement dans le chargement cyclique et les exemplaires restent intacts après le fait d'appliquer 5000 cycles. Les résultats de mon tonic et le chargement post-cyclique ont prouvé que les paramètres de force d'échantillons de béton bitumineux ne changent pas de façon significative après être fait subir à loa sismique

Keywords : asphalt concrete, earth dam, cyclic triaxial test, monotonic triaxial test, strength parameters

1 INTODUCTION

Although several numerical studies have been performed on behavior of earth fill dams with asphalt concrete core, very few laboratory studies are available about dynamic and static behavior and strength parameters of asphalt concrete. The aim of present study is to investigate behavior of asphalt concrete used in core of earth fill dams under monotonic and cyclic loading.

More than 120 cyclic triaxial tests and 13 monotonic tests were conducted to attain strength properties of asphalt concrete. Tests were conducted with cyclic and static triaxial apparatus of Advanced Geotechnical Laboratory in Sharif University of Technology. Effects of maximum aggregate size, bituminous content, confining pressure, number of cycles, frequency and temperature on strength parameters of asphalt concrete are illustrated.

In the present study, bitumen of type B60 was selected as binder and aggregates used were crushed limestone which is an alluvial stone with a low strength. Gradation of aggregates complies with Fuller criteria as it is recommended by ICOLD (ICOLD 1992).

In order to investigate effect of maximum aggregate size and bituminous content on asphalt concrete properties, specimens were prepared with two different maximum aggregate sizes (M.A.S.) 25.4 and 12.7 mm. A preliminary range for optimum bituminous content was determined on basis of uniaxial compression tests. Based on the range obtained from these tests the bituminous content (b) for specimens with M.A.S. of 12.7 mm was specified as 5.5, 6 and 6.5% and for specimens with M.A.S. of 25.4 mm was specified as 5, 5.5, 6 %.

The procedure of preparation and compaction of asphalt specimens complied with ASTM standard D1074 except from some minor differences in the applied mould and specimens' height. The laboratory main specimens were prepared in a mould with a diameter of 101.6 mm and a height of 292.1 mm in order to produce specimens with height of about 200 mm and a diameter of about 100 mm.

2 BEHAVIOR OF ASPHALT CONCRETE UNDER CYCLIC LOADING

The specimens were loaded under isotropic condition ($\sigma_1/\sigma_3=1$). Tests were stress controlled and a two-ways loading type was applied. The confining pressure (σ_3) was varied in three levels of 200, 400 and 600 kPa. This is close to the range of pressures subjected to the asphaltic core in dams. After isotropic loading, different levels of cyclic deviator stress applied depending on the level of confining pressure. Most of the tests were conducted at temperature of 25°C and with 1 Hz loading frequency, but to examine the effect of temperature and frequency, some tests were performed at temperature of 18°C and with loading frequencies of 0.2, 0.5, 2 and 5 Hz. Specimens were covered with two rubber membranes and then placed in triaxial cell in order to be tested in a dry condition. Figure 1 shows hysteresis loops in cycles 1, 5, 10, 20, 50, 100, 150 and 200.

It can be observed that amplitude of cyclic stress remains constant as number of cycle increases and amplitude of axial strain changes slightly. The remained strain after applying 200 cycles of loading was less than 0.06% for all samples. This shows that the applied loads were in elastic part of stress- strain curve for asphalt concrete. Some tests were conducted to examine the effect of high number of cycles of loading. No sign of degradation or cracking was observed after applying 5000 cyclic loads. This shows very little cracking potential due to cyclic loading in an asphaltic core. It can be concluded that asphaltic core behaves appropriately under seismic loads equal to size applied in this research.

2.1 *Compression and extension behavior of asphalt concrete*

After applying 200 cycles of loading the remained strain was positive in some samples and negative for others. Thus, we can divide the behavior of asphalt concrete into two categories; extension and compression. Figure 2 shows how remained strain varies with confining pressure, deviator stress, M.A.S.

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and bituminous content. It can be concluded that for confining stress of 200 kPa all samples show compression behavior. On the other hand, for higher confining pressures compression behavior occurs for lower deviator stresses, but as deviator stress increases behavior of samples gradually inclines to extension. It shows that in upper part of asphaltic core displacements are compressive and in lower part in the case of high cyclic loads extensive displacements may occur. Also it can be observed that by increasing bituminous content and decreasing M.A.S. from 25.4 to 12.72 samples' behavior approach to extension.

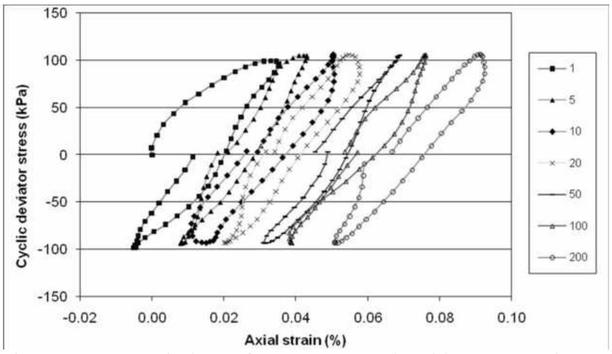
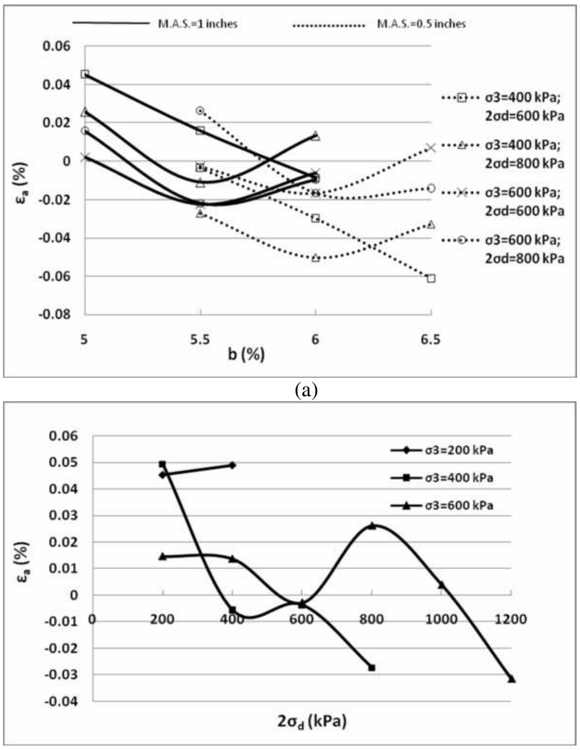


Figure1. Hysteresis loops for test on sample with M.A.S.=25.4 mm, b=5%, σ3=200 kPa, σ_d=200 kPa, T=25°C



(a)

(b)

Figure2. Variation of remained strain after 199 cyclic loading with a) bitumen content; b) deviator stress and confining pressure for M.A.S.=12.7 mm and b=5.5% at T= 25°C

3 DYNAMIC PARAMETERS OF ASPHALT CONCRETE

3.1 *Calculation of dynamic properties of asphalt concrete*

Dynamic behavior of asphalt concrete is usually characterized on basis of shear modulus and damping ratio derived out of deviator stress-axial strain loops. Definition and method for calculating G (secant shear module) and D (damping ratio) were based on ASTM standard D3999. Value for Poisson's ratio for asphalt concrete was considered 0.45 in calculations (Nakamura, 2004; Sausa & Monismith, 1988)

Although shape of hysteresis loops are almost the same in compression and extension, two other types of shear modulus (G_c and G_e), and damping ratio (D_c and D_e), were defined to investigate the difference of parameters in compression and extension. The method for calculation of these parameters is illustrated in Figure 3.

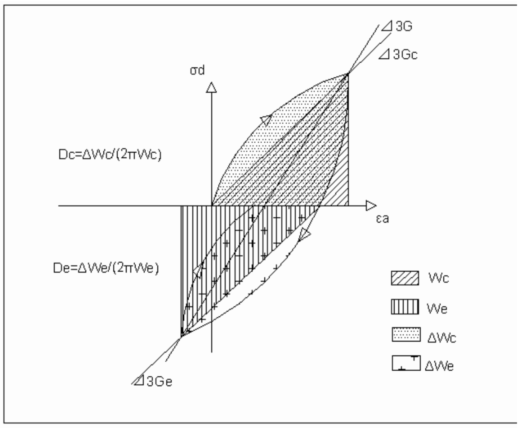


Figure 3. Calculation of Gc, Dc, Ge, De

3.2 *Shear modulus and damping ratio for different samples*

Figures 4 to 6 shows variation of G, Gc. Ge, D, Dc and De with shear strain for asphalt concrete samples in confining pressure of σ_3=600 kPa and at temperature of 25°C.

It can be concluded that shear modulus decreases and damping increases with a small rate as shear strain increases. Comparison between different types of G and D shows that G is greater than Gc and Ge and Gc/Ge ranges between 1.16 to 1.28 for different samples. Also results show that value of D is greater than Dc and De. Although results obtained for Dc and De is sparse but in most cases value of De is greater than Dc. Thus it can be concluded that stiffness of asphalt samples in compression is greater than in extension, vice versa damping in extension is greater than in compression.

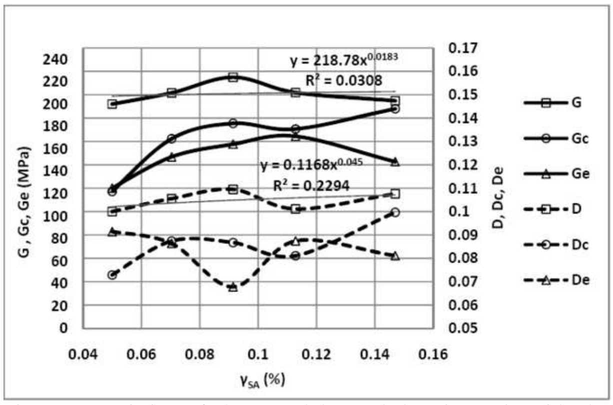


Figure 4. Variation of shear modulus and damping ratio with shear strain for sample with M.A.S. = 12.7 mm, b=5.5% and σ_3=600 kPa

3.3 *Effects of different parameters on dynamic properties of asphaltic samples*

3.3.1 *Confining pressure (σ_3) and deviator stress(σ_d)*

An increase in confining pressure causes asphalt concrete samples to show higher shear modulus and lower damping ratio. This is illustrated in Figure7. Also as it can be seen deviator stress does not influence shear modulus and damping significantly.

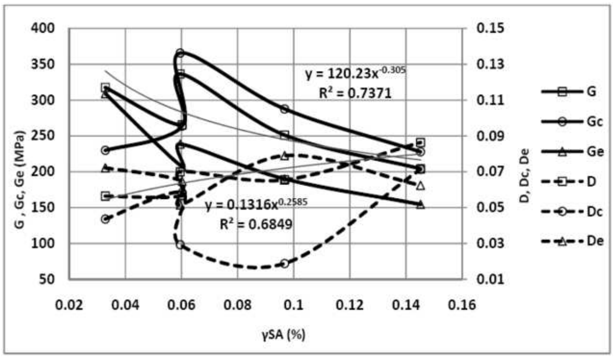


Figure 5. Variation of shear modulus and damping ratio with shear strain for sample with M.A.S.= 25.4 mm, b=5% and σ_3=600 kPa

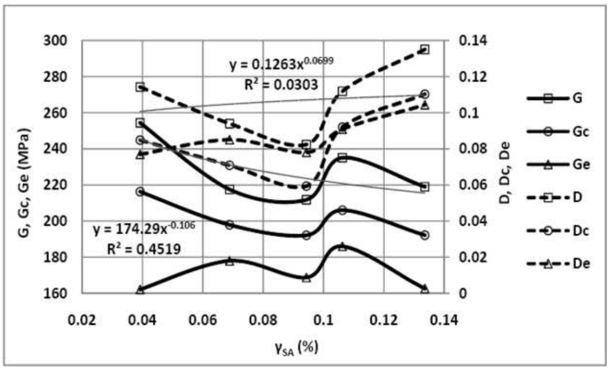


Figure 6. Variation of shear modulus and damping ratio with shear strain for sample with M.A.S. = 25.4 mm, b=6% and σ_3=600 kPa

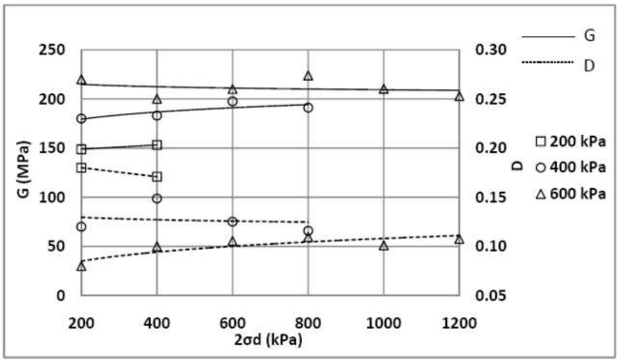


Figure 7. Effects of confining pressure and deviator stress on G and D, M.A.S. = 25.4 mm, b= 5.5 % and T= 25°C

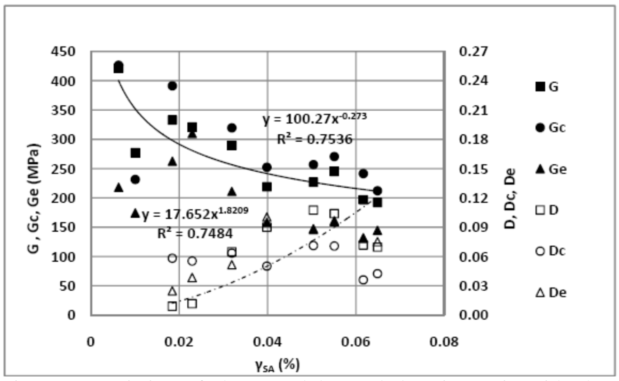


Figure 8. Variation of shear modulus and damping ratio with shear strain, M.A.S.= 12.7 mm, b= 5.5%, σ_3=400 kPa and T= 18°C

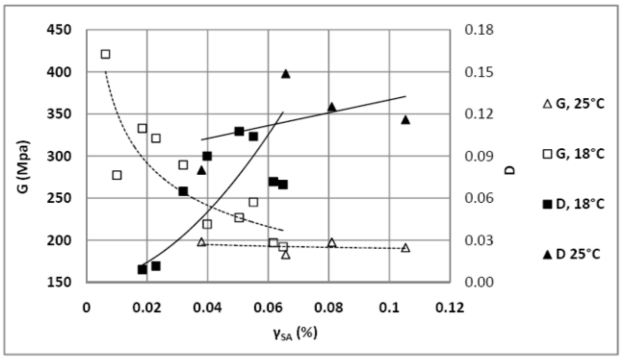


Figure 9. Effects of temperature on G and D, M.A.S.=12.7 mm, b =5.5% and σ_3=400 kPa

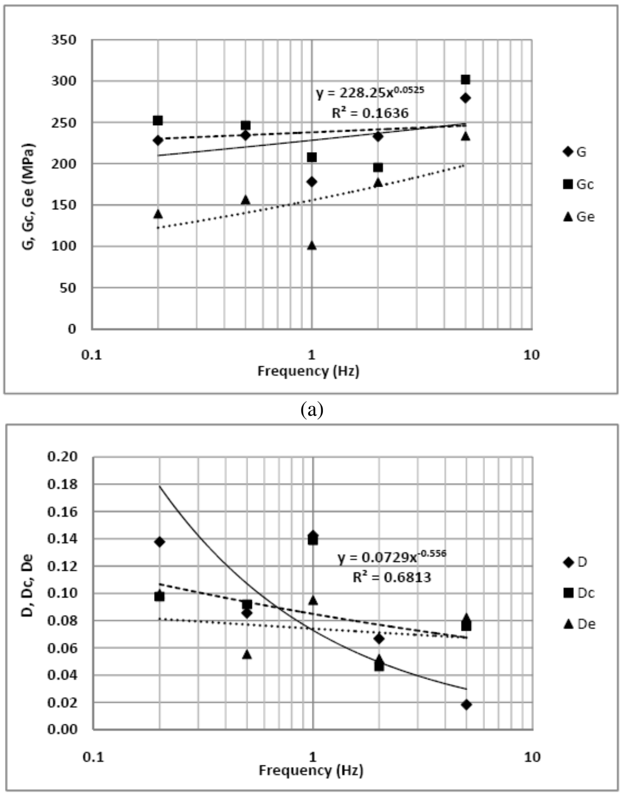


Figure 10. Effects of loading frequency on a) G; b) D, M.A.S.=12.7 mm, b =5.5%, T=18°C

3.3.2 *Temperature*

Figure 8 shows results of test on sample with M.A.S.= 12.7 mm and b= 5.5% with confining pressure of 400 kPa in temperature of 18•C. Also Figure 9 compares the results in temperature of 25 and 18•C. It can be concluded that temperature has a significant effect on dynamic parameters. Shear modulus increases and damping decreases as temperature declines.

3.3.3 *Loading Frequency*

Figures 10 shows how shear modulus and damping ratio varies with cyclic loading frequency for sample with M.A.S.=12.7 mm and b =5.5% at temperature of 18°C. As it can be observed, shear modulus increases and damping decreases as loading frequency increases.

4 BEHAVIOR OF ASPHALT CONCRETE UNDER MONOTONIC LOADS

Monotonic tests were conducted on 7 undistributed samples and 6 samples which were subjected to cyclic loading up to 200 cycles or more, in the previous section of tests. Tests were conducted at temperature of 18° and confining pressure of 400 kPa were exerted to specimens. Strain rate during loading was set 0.1 mm/min. Stress- strain curves of monotonic and post-cyclic tests for sample with M.A.S.= 12.7 mm and b= 5.5% is shown in Figure 11 for instance.

Table 1 and 2 show the total results for different samples obtained from monotonic and cyclic tests respectively.

Two last columns in Table 2 show percent of difference of failure stress and Young's modulus between samples tested in monotonic and in post-cyclic condition. Results show that applying cyclic loads to asphaltic samples induce reduction of about 6 to 13 % in E and 1.5 to 7.5 % in σ_{1f} which shows that strength parameters of asphalt concrete samples does not change significantly after being subjected to cyclic loads.

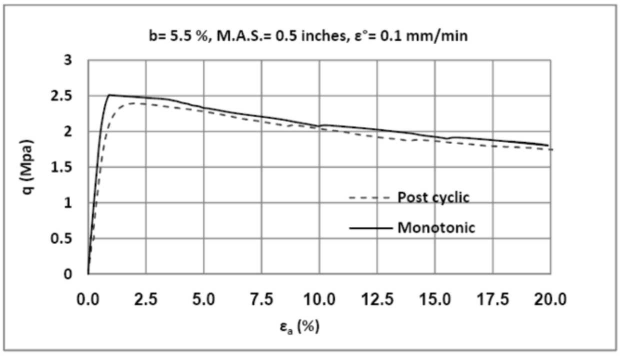


Figure 11. Stress- strain curves obtained from monotonic and post-cyclic tests on sample with M.A.S.= 12.7 mm and b= 5.5%

Table 1. Results of monotonic triaxial tests on asphalt concrete samples

M.A.S. (mm)	b (%)	axial stress at failure (σ_{1f}) (MPa)	σ_1/σ_3	Axial strain at failure (%)	Young's Modulus at 1% strain E (MPa)
12.7	5.5	2.91	7.28	0.90	246.8
12.7	6.0	3.02	7.55	1.18	268.7
12.7	6.5	2.73	6.83	2.05	223.1
25.4	5.0	2.70	6.75	1.74	210.0
25.4	5.5	2.73	6.83	2.11	210.2
25.4	6.0	2.43	6.08	1.94	190.9

Table 2. Results of post-cyclic tests on asphalt concrete samples

M.A.S. (mm)	b (%)	σ1f (MPa)	εf (%)	E1% (MPa)	Percent of Difference E (%)	Percent of Difference σ1f (%)
12.7	5.5	2.79	2.04	217.0	12.84	4.10
12.7	6.0	2.95	1.10	252.2	6.37	2.32
12.7	6.5	2.86	2.86	244.3	9.08	-4.78
25.4	5.0	2.66	2.01	213.3	-1.56	1.36
25.4	5.5	2.53	2.09	198.0	5.98	7.62
25.4	6.0	2.62	2.11	197.7	-3.54	-7.56

In some cases final strength and Young's modulus of sample in post- cyclic condition is a bit larger than in Monotonic condition. The reason could be the inherent difference between two similar samples.

It can be concluded that value of final strength and also Young's modulus reaches its maximum value at bituminous content of 5.5% for samples with M.A.S. of 25.4 mm and at 6% for samples with M.A.S. of 12.7 mm. Also samples with M.A.S. of 12.7 mm show higher strength and stiffness than samples with M.A.S. of 25.4 mm having same bituminous content.

Axial strain at failure increases as bituminous content of samples increases. It shows that increasing bituminous content cause more ductility in specimens. Also results show that in a same bituminous content sample with larger M.A.S. fails in a higher strain level.

Shape of specimens after failure was tubby and a 45° failure plane was observed in all specimens.

5 CONCLUSIONS

From the results of this study the following conclusion can be deduced:

1-Asphalt concrete behaves appropriately even after 5000 cycles of loading. No sign of cracking and degradation was observed in samples.

2-The amount of shear modulus decreases and damping ratio increases slightly with increasing the cycles..

3- Increasing the confining pressure cause considerable increase in shear modulus and a decline in damping ratio. The influence of confining pressure increases as deviator stress increases.

4- As frequency increases and temperature decreases, shear modulus increases and damping ratio decreases. Results illustrate that temperature has a great effect on dynamic properties of asphalt concrete.

5- Results of monotonic and post-cyclic loading show that strength parameters of asphalt concrete samples do not change significantly after being subjected to seismic loads.

6- Final strength was ranged between 2.5 to 3 MPa depends on M.A.S. and bituminous content of samples. Also Young's modulus varies in the range of 190-270 MPa.

7-Higher bituminous content and M.A.S. cause asphalt concrete to fail in larger strain levels.

8- Samples with smaller M.A.S. show larger strength and stiffness.

9- Shape of specimens after failure was tubby and a 45° failure plane was observed in all specimens.

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