Cyclic load triaxial test procedures for soils in transportation engineering

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Abstract. Unbound granular base course is built in pavement structures between subgrade and bound base course. Its main function is bearing capacity - load transfer from upper layers to subgrade. For its successful design, one of the required parameters is resilient modulus. Resilient modulus describes behaviour of unbounded materials at various load conditions, and is defined as the ratio of the applied cyclic stress to the elastic strain. It can be determined with cyclic triaxial test that gives good simulation of stresses and strains which are result of traffic loads. In this paper resilient modulus testing procedure will be described with the emphasis on European Standard (EN 13286-7). Furthermore, it will be given comparison of European standard with other test procedures.

1. Introduction
Large deformations (rutting) and cracks on the pavement surface can lead to traffic safety risk due to possibility of water collection, extra costs from faster tyre wear and higher fuel consumption due to higher friction between tyres and pavement, higher road maintenance costs and the reduction of the driving comfort. AASHO road test [1] have shown that rutting is affected by base and subbase course deformations by 59%. Hence, good design of those layers is necessary. Until the Second World War, road thickness was designed empirically considering traffic load as static [2]. Increase in traffic quantity and traffic loads resulted with numerous tests and traffic loads were soon observed as dynamic. According to [3], first repeated load tests were conducted with plate load tests with smaller amount of load repetitions. However, limitations were noticed shortly, therefore the laboratory testing soon began. Since triaxial test offered the possibility of application of different stress levels in time, respectively reproduction of critical soil conditions, first triaxial tests with repeated load have started [3]. The first comparisons of results gained in repeated load tests and static tests [4, 5] have shown differences in obtained moduli, and it was concluded that repeated load tests should be carried out for soils under traffic loading [3].

2. Resilient modulus and permanent deformations
The results of cyclic triaxial test are resilient modulus, elastic and plastic deformations. Resilient modulus is crucial for mechanistic-empiristic approach used for pavement design procedures. It was introduced by [4] as ratio of dynamic deviator stress and axial resilient deformation. Plastic deformations are permanent deformations that important parameter for flexible pavement design. They are accumulated with every stress cycle, and after certain number of cycles their accumulation becomes negligible. This was shown in AASHO road test [1], where larger ruts were recorded during the first year of the test compared to the second year. Haynes and Yoder [6] have tested base layers and recorded accumulation of permanent deformations even after 100,000 load cycles. Morgan [7] has carried out tests on sand specimens and recorded negligible accumulation of permanent deformations after 2 million
loading cycles, while [8] found the stabilization of permanent deformations after 100,000 cycles (according to [9]).

Resilient modulus and permanent deformation values are under impact of several properties, some of which are density, grading, moisture content, grain shape and surface roughness, stress level. Seed and Chan [10] were among first that started repeated triaxial load tests to determine impact of load duration on deformation development of silts. They concluded that the resilient modulus increased as the load duration decreased (according to [3]). The impact of water content on the values of resilient modulus and permanent deformation was studied to [6, 11-13]. The tests showed that resilient modulus decreases and permanent deformation increases as the water content increases. The resilient modulus increases as the specimen density increases according to [12-15]. Hicks and Monisimith [15] have shown increase in resilient modulus with increasing particle angularity or surface roughness. The same have shown [12] comparing rough, angular materials with rounded gravel. The results of the research of fine content impact on resilient behaviour and/or development of permanent deformations, conducted by [11, 15], have shown that resilient modulus decreases and permanent deformations increases with the increase of the fine content in the material.

3. Test procedures

Although numerous triaxial repeated load tests were carried out, only in 1982, first standard for resilient modulus test was adopted – AASHTO T274. Nowadays, after several revisions, AASHTO T307-99 is currently valid. Following the adoption of first standard, new standards and regulations were created. NCHRP 1-28A [16] gives procedure for laboratory determination of resilient modulus for unbound granular base and subbase materials, which is harmonized with AASHTO and FHWA test procedures. Australia gives AG:PT-T053-07 [17] for resilient modulus and permanent deformations testing for unbound granular materials with repeat load triaxial test, while Europe in EN 13286-7 [18] standard gives procedure for cyclic load triaxial test for unbound mixtures. Several researchers have proposed recommendations or test procedures for determination of resilient modulus and/or permanent deformations [19-21].

3.1. EN 13286-7

European standard EN 13286-7 [18] defines procedure for resilient modulus and permanent deformations testing at lower or higher stress levels and with constant or variable confining pressure. For test conduction, the triaxial cell is needed along with loading frame for axial load, displacement transducers (Figure 1), as well as pressure control box, test control and data capture system.

Figure 1. Triaxial cell with displacement transducers [18].

Cyclic load triaxial test is carried out in phases – the conditioning of the specimen phase and the resilient testing phase, and, if permanent deformations are to be determined, a third phase for permanent behaviour testing can be added. The test begins with conditioning phase, which aim is stabilization of...
deformation and achievement of stable resilient behaviour of the specimen. In that phase large number of cycles are applied at defined confining pressure and deviator stress. Some researchers have investigated the required duration of the conditioning phase. Barksdale and Hicks [22] found that 1,000 load cycles are sufficient for cohesionless specimen conditioning (according to [3]). The European standard [18] gives a higher number of load cycles (20,000) with the possibility of lesser number of cycles if stable resilient behaviour of the material is achieved. The resilient modulus test phase is carried out at greater number of stress paths with lower number of load cycles. Barksdale and Hicks [22] concluded that, after conditioning, 50 to 100 load cycles is sufficient for resilient modulus testing of cohesionless materials and that with such small number of load cycles, specimen can be tested at different stress states (according to [3]). Depending on the test method, European standard [18] gives various stress paths in duration of 100 cycles each. Permanent deformations are tested at larger number of cycles and according to [18] can be tested for one stress path at 80,000 cycles, or at several different stress paths (multi-stage loading) in duration of 10,000 cycles each.

3.2. Comparison of test procedures
The test procedures have its differences in regard of sample dimensions, maximum particle size limitations, sample formation, duration of the conditioning phase, number of stress paths applied in resilient modulus test phase along with its levels (confined and deviator stress), response measurement, number of cycles used for result analysis (resilient modulus computation). Comparison of test requirements of EN 13286-7 with several other test procedures is given in Table 1.


| Procedure | Specimen | Specimen preparation | Load wave form and duration | Stresses and number of cycles | Response measurement and results |
|-----------|----------|----------------------|----------------------------|------------------------------|---------------------------------|
| EN 13286-7 [18] | Øₜ > 5xDₘₐₓ | Vibro compression (1 layer, without membrane) or vibrating hammer (>6-7 layers, with membrane) | No waveform and no duration, frequency of loading between 0.2 Hz and 10 Hz | Conditioning 20,000 cycles (variable or constant σₚ with high or low stress levels); Mₚ testing 100 cycles each stress path (17 stress paths for variable or 29 for constant σₚ with high or low stress levels); εₛ testing single-stage loading 80,000 cycles (variable or constant σₚ) or multi-stage loading 10,000 cycles each stress path (30 stress paths for low stress levels, 28 for high) | 1) 3 internal* axial LVDTs and 3 internal* radial LVDTs 2) 2 internal* axial LVDTs and 2 flexible epoxy resin rings Mₚ computed as avg. of last 10 cycles |
| AASHTO T307 [23] | Øₜ > 5xDₘₐₓ | Type 1 vibratory compaction (6 layers, with membrane) | Haversine waveform, cycle duration 1-3.1 s with load duration 0.1 s | Conditioning 500-1000 cycles (σₛ = 41.4 kPa, σₑ = 27.6 kPa subgrade soil, σₑ = 103.4 kPa, σₑ = 103.4 kPa base/subbase soil); Mₚ testing 100 cycles each stress path (15 stress paths; σₛ = 13.8-41.4 kPa, σₑ = 13.8-68.9 kPa subgrade soil, σₑ = 20.7-137.9 kPa, σₑ = 20.7-275.8 kPa base/subbase soil) | 2 external* axial LVDTs Mₚ computed as avg. of last 5 cycles |
| NCHRP 1-28A [16] | Dₘₐₓ= 25.4 mm | Type 1 impact (6 or 8 layers) or vibratory compaction (6 layers, with membrane), Type 2 vibratory compaction or static loading or kneading (5 layers, if needed with membrane) | Haversine waveform, cycle duration 1 s with pulse 0.1 s (base/subbase) or 0.2 s (subgrade) | Conditioning min. 1,000 cycles (σₛ = 27.6 kPa, σₑ = 53.8-227.7 kPa - depends on course base, subbase, subgrade); Mₚ testing 100 cycles each stress path (20 stress paths for granular subgrades, 16 fine graded subgrades, 30 for base/subbase; σₑ = 13.8-138 kPa, σₑ = 9.7-993.6 kPa - depends on course base, subbase, subgrade) | 2 internal* axial LVDTs - middle half of the specimen Mₚ computed as avg. of last 5 cycles |
| AG-PT1031 [17] | Dₘₐₓ = 19 mm (up to 5% > 19 mm) | Hammer with standard (5 layers) or modified effort (8 layers), Compaction without membrane | Cycle duration of 3 s, rise and fall up to 0.3 s and load pulse 1 s | Conditioning 1,000 cycles (σₛ = 50 kPa, σₑ = 100 kPa); MR testing 200 cycles each stress level (66 levels; σₑ = 20-150 kPa, σₑ = 100-600 kPa) + 50 cycles preconditioning; εₛ testing 30,000 cycles (σₛ = 50 kPa, σₑ = 150-550 kPa - depends on course base, subbase) | 2 LVDTs internal or external* for δₑ, 1 LVDT external* for δₑ Mₚ computed as avg. of last 6 cycles |

Øₜ – specimen diameter, Hₜ – specimen height, Dₘₐₓ – maximum aggregate diameter, Mₚ – resilient modulus, εₛ – permanent strain, σₛ – confining pressure, σₑ – deviator stress, δₑ – vertical resilient displacement, δₑ – vertical permanent displacement, * internal/external – load cell internal/external, LVDT – linear variable displacement transducers

4. Conclusion
The resilient modulus and permanent deformations are one of the most important properties for pavement design. They can be determined in cyclic load triaxial test for which exist several test procedures, one of which is European standard EN 13286-7. The test provides excellent traffic simulation on tested materials where different conditions can be observed (for example gradation, density, moisture content). In this paper important aspects of testing procedure following EN norm are discussed and compared to other procedures suggested by other norms.
5. References

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