

Comparison of Internal Friction Angles of Soils for Foundation Engineering

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Abstract. The aim of the publication is to evaluate the indicative modules of the deformation of fine-grained, sandy and gravelly soils. Deformation modulus is one of the most important geotechnical properties in terms of geotechnics. The reason is that it is most important from the point of assessing subsidence of buildings and expresses the characteristics that we call compressibility. It is evident that differences in the modulus of deformation are very important, among the classes of fine-grained, sandy and gravelly soils. Maximum indicative value of deformation modules is 30 MPa for fine-grained soils. It is 100 MPa for sandy soil and 500 MPa for a gravelly soil. From this trend it is apparent that the geological conditions have different characteristics in terms of impact on the subsidence of buildings in these important groups of sediments.

1. Introduction

Evaluation of Deformation modules is significant geotechnical characterization, used to evaluate the subsidence of buildings in a specific geologic environment. This is one of the most important geotechnical characteristics together with a bulk density and shear strength. This is expresses the characteristics that we call compressibility. The presented study evaluates the orientation deformation modules, based on the statistics of the *CSN 73 1001 Foundation of structures. Subsoil under shallow foundations*. This standard is already now replaced by the new standard, but in this standard does not include these characteristics. If we want to gain basic knowledge about these properties, these characteristics need to evaluate. This fact is the aim of presented publication.



2. Comparison of soil properties in terms of the angle of internal friction

Group of fine **grained soil** (Figure 1) is evaluated first. The minimum values for the lower limit values of soft consistency in the evaluation study. The lowest values have class of foundation soil F7 and F8, i.e. silt and clay with high, very high and extremely high plasticity. The value of deformation modulus is 1 MPa. Higher values class F5 and F6, i.e. silt and clay with low and medium plasticity 1.5 MPa. Then deformation modulus increases due to the content of sand in the clay to 2.5 MPa for class of foundation soil F4. For Class F3 is a further increase because sandy silt (3 MPa), instead of the sandy clay. Admixture of gravel in the clay causes subsequent increase to 4 MPa. If we still have silt instead of clay, i.e. gravel, so this consistency condition reaches its maximum at a 5 MPa.

The following section will deal with the second lowest group in the order of values at deformation modules. This is a maximum at the soft consistence and the minimum value of rigid consistence. Regarding values, so the class F8 of foundation soil, clay with high, very high and extremely high plasticity has the lowest values, i.e. 2 MPa. Then, in this state of consistency is increased to 3 MPa. It relates to a class of foundation soils F5, F6 and F7. This means that it is a silt with all the conditions of the plasticity, and the clay with low and medium plasticity. For class F4 further value increase to 4 MPa because of the sand contained in the clay. The value is 6 MPa at analogous class of foundation soil F3. The value is 5 MPa at a maximum of soft consistency and at a minimum values of a rigid consistence. This means that the two mentioned conditions already have a minimum difference. A similar trend is at class F2 for gravelly clay. Wherein the minimum value of a firm consistence is 7 MPa and a maximum value of soft consistency is 8 MPa. Class F1 with a value of 10 MPa has the highest value in these limits of Atterberg. In two of Atterberg limits, i.e. solid and rigid leads to further increases. While at firm state we are dealing with about lower minimum limit values, and at the rigid state is engaged in the upper maximum limit of values. We distinguish the interval from 4 MPa to 6 MPa. It leads to minimal increases Edef between classes F4 till F8. For Class F3, sandy loam leads to a greater increase. Both of these conditions of consistency here have a value of 8 MPa at minimum and maximum values. For class F2 and F1 is the steeper increase, where the maximum value of rigid consistence is 20 MPa, the minimum value of a firm consistency is only 12 MPa. There was noted the biggest difference between the recorded states under this paragraph.

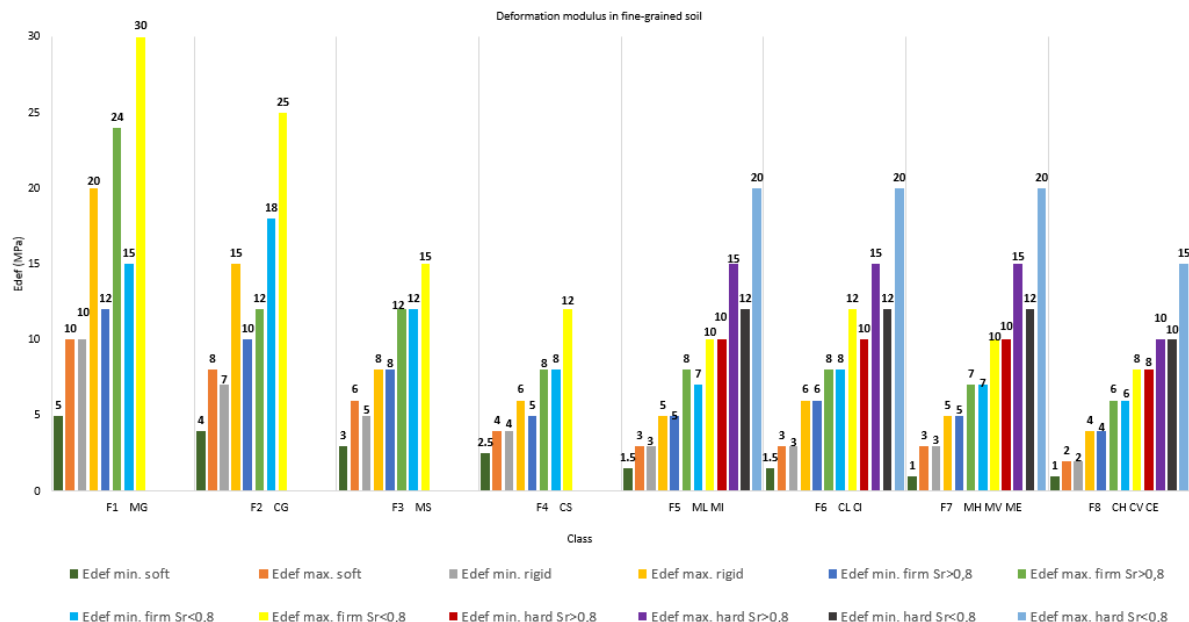


Figure 1. Deformation modulus in fine-grained soil according to [2]

Firm consistency condition ($S_{\text{sat}} > 0.8$) with its maximum values and firm consistency condition ($S_{\text{sat}} < 0.8$) with minimum values are the other two conditions of the consistency with similar values. Deformation modulus reaches 6 MPa at class F8 for both states. Values of deformation modulus are the

same also in F7 and F6 in which is gradually increased within each of the classes 1 MPa. F5 class is an exception, where the maximum value E_{def} of firm consistency reaches 8 MPa and a minimum value of firm consistency 1 MPa or less, i.e. 7 MPa. However, the values are identical for both states in the case of class F4 and F3. They grow from a value of 8 MPa for class F4 to 12 MPa for class F3. The difference between these two classes is already significant in the case of class F1 and F2. This is 6 MPa at class F2 and 9 MPa for class F1, where the maximum value reaches a maximum firm consistency, with a value of 24 MPa.

A similar trend also shows a pair of firm consistency condition ($S_{sat} < 0.8$) with maximum values and hard consistency condition ($S_{sat} > 0.8$) with maximum values. For class F8 and F7 achieve the same numbers, i.e. of 8 MPa and 10 MPa. Whereas hard consistency condition ($S_{sat} > 0.8$) with maximum values holds this value until class F5. For Class F1 until F4 is no longer defined and values must be investigated by tests. However, firm consistency condition ($S_{sat} < 0.8$) with maximum values continued to grow to a value 30 MPa for class F1. This value is also the highest in the entire range of evaluated classes and Atterberg limits.

Hard of consistency condition, with degree of saturation ($S_{sat} > 0.8$) with maximum values is given for class F8 to F5. The value is 10 MPa for class F8. For Class F7 to F5, the value is held at 15 MPa.

Hard of consistency condition ($S_{sat} < 0.8$) with minimum values and hard of consistency condition ($S_{sat} < 0.8$) with maximum values represent the last couple of assessed values. They are defined only for class F8 to F5. While both of consistency conditions show the same trend. Value is 10 MPa and 15 MPa for class F8. For class F7 to F5 value is 12 and 20 MPa. Properties of grained soils, mainly the issues a load of soils is given in publications [15, 7].

Another group consists of **sandy soil** (Figure 2). The lowest value of the deformation modulus was found in sandy sediments in the class S5 of foundation soils, i.e. clayey sand. It is 4 MPa. This condition is characterized at state of compaction for the minimum ID of 0.33 to 0.67 and the minimum values 0.67 to 1.0. Similarly, it is for the class F4, where E_{def} is 5 MPa and class of foundation soil is characterized by sandy clay. These values correspond to the minimum values at soft consistency for class F1 and F2 at fine-grained soil. This is logical, because their particle size distribution has certain similarities. The differences are in that state of consistency, only in the representation of percent. To further increase occurs in the class S3 to 12 MPa, for Class S2 to 15 MPa and for Class S1 that is 30 MPa. It concerns the minimum values of the state of compaction ID from 0.33 to 0.67. From the class S3 leads to a substantial growth in value of deformation modulus at the minimum values of the state compaction of ID from 0.67 to 1.0. For Class S3 was an increase from 12 MPa to 17 MPa, representing an increase of 5 MPa. For class S2, the increase is increased to a value of 15 MPa while 15 MPa grew to 30 MPa. This difference was for Class S1 even higher, i.e. about 20 MPa. There was an increase from 30 MPa to 50 MPa. It is a sandy soil with the highest proportion of the sand fraction that is the reason for this increase in class S1 and S2. This means that the compaction plays a greater role, because there is a greater difference in the porosity between the two states. State of class S1 well graded sand is characterized by an even higher growth than in the S2 class poorly graded sand. It follows that the area of touch the grains among themselves when changing compaction is greater for well-grained sand. Increasing the contact area of the consequently causes an increase the area.

The state of compaction of sandy soils with an ID from 0.33 to 0.67 represents another group from the viewpoint of increasing the modulus values of deformation, whereby these are maximum values. At the same time, the state of compaction with an ID from 0.67 to 1.0 is the second state with the highest values of deformation modulus of sandy soils. These are also maximum values. The group begins with a minimum value for Class of the foundation soil F5 with the value 12 MPa, and these two states have the same value. For class of the foundation soil S5 follows the same pattern. Both of these conditions have a value of 15 MPa. This means that there is between two of these classes, the difference of 3 MPa.

However, in Class S3 sand with fine soil, there is already a difference in values between the two of these states compaction. The smaller value of 17 MPa, has state with an ID from 0.33 to 0.67 (maximum). However, the compaction characterized by the ID value from 0.67 to 1.0 has a value of 25 MPa. To further an increase in values occurs in the class S2 poorly graded sand. Worse values there achieved compaction of 35 MPa and greater compaction is characterized by a value of 50 MPa. This means that the difference between these two states is 15 MPa. For class S1 occurs gradation

difference up to 40 MPa. Worse compaction is characterized by 60 MPa and better compacted sand material has a value of 100 MPa. This means that the above described difference between class S1 and S2 well and poorly sand achieved in this range even larger difference values.

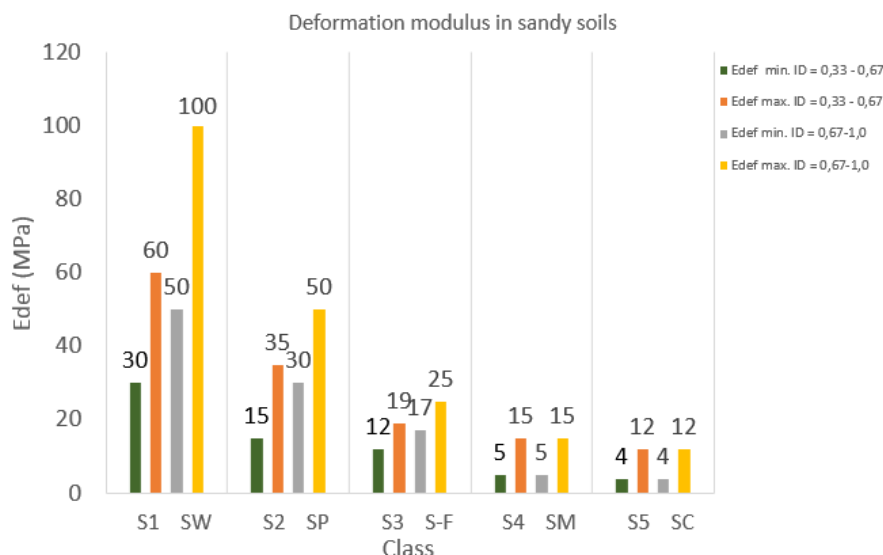


Figure 2. Deformation modulus in sandy soil according to [2]

The maximum recorded value of deformation modules is 30 MPa for sandy soils. This corresponds to a value of sand S1 with a minimum limits of values characterized by compaction ID from 0.33 to 0.67 or class S2 at compaction 0.67 to 1.0 (the minimum limits range of values). This means that if we want to talk about similar values of deformation modulus between the fine grained and sandy soils, so we can talk only about classes S3, S4 and S5, as in these soils is the content of fine-grained soils. For Class S1 and S2 are substantially higher deformation modulus and unmatched with fine-grained soils. Only Class S2 at the poor state of compaction of 0.33 to 0.67, may reach the value 15 MPa. This, however, only in connection with the fact that there is only a lower boundary of values achieved with these boundary conditions. Properties of sand in terms of their suitability for foundations of structures were also tested under the publications [14, 9, 12] and [11].

The last group are the **gravelly soils** (Figure 3). To the class of the foundation soil G5 clayey gravel are recorded lowest values of deformation modulus which is characterized by a value of 40 MPa. This value is characteristic for low compaction with ID value from 0.33 to 0.67 at the minimum value that achieves this state (It also applies to the minimum values of compaction from 0.67 to 1.0). Similar statements can be said about the value of G4 silty gravel with the value about 20 MPa higher (60 MPa). For G3 gravel with fine-graded soil, between these two states is already difference, the minimum values of worse compaction are characterized by 80 MPa and in better values are characterized by 90 MPa. Only classes of the foundation soil G3, G4, G5, can partially compare with classes S1 and S2 due to the fact that in these classes is additive fine-graded soil, which causes deterioration of the properties of these classes. Class G2 has poorer compaction at 100 MPa and at 170 MPa, has a better compaction. This means that for this class G1 represents the difference up to 110 MPa. Worse condition has 250 MPa and a better condition has 300 MPa.

Class G5 achieves 60 MPa and class G4 reaches 80 MPa in both these states of compaction, if we assess the state of compaction in gravelly soils with ID from 0.33 to 0.67 with the maximum values, and we will evaluate better the state of compaction of 0.67 to 1.0 (also with its maximum value). For G3 is 90 MPa for the worse state of compaction and 100 MPa for a better state of compaction. For G2 is significantly improved properties wherein worse condition reaches values of 190 MPa and 250 MPa is better. This means that between the two values is a difference of 60 MPa. Class G1 reaches the best

values of all soils, where the better condition has a value of 390 MPa, and the state with the best compaction reaches 500 MPa. This value is the highest of all the indicative stated. Gravelly soils in terms of their suitability as of the foundation soil are at the publication [16, 5] and [3]. The authors stated, first mentioned deformation modulus, but also the value of deformation and deformation under pressure. Soil properties is important to consider especially in the context of the given local conditions and difficulty of that of a particular construction in [1, 4, 6, 13] and [10, 16, 17]. Different requirements are so strong in the case of embankments, or in the case of dams.

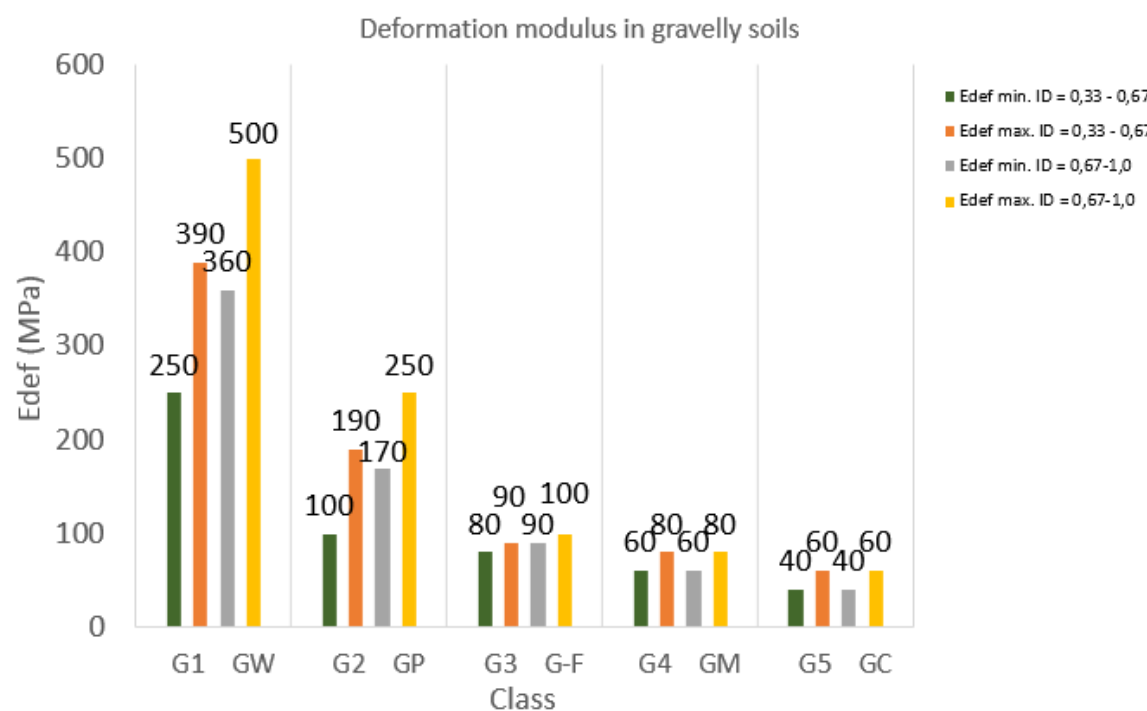


Figure 3. Deformation modulus in gravelly soil according to [2]

3. Conclusions

Deformation modulus is significant geotechnical characteristics, in which perhaps are most visible differences between the characteristics of different classes of foundation soils. This assertion is based on indicative values that together achieve fine-grained, sandy and gravelly soils. Between them is a big difference. This difference does not show so much at other geotechnical properties. The minimum value of the fine grained soil is 1 MPa and a maximum value is 30 MPa. For sandy soils is the lowest value 4 MPa and the highest reaches 100 MPa. Lowest approximate value at gravelly soils is 40 MPa and the highest value is 500 MPa. This means that the maximum value at gravelly soil for class G1 is up to 5 times higher than the maximum value with the same compaction at of sandy soils class F1. The difference between the highest value of sandy soils S1 (100 MPa) and F1 class (30 MPa) is about three times. From all of the above facts it is evident that the differences are very significant between the fine-grained, sandy and gravelly earths and needs to be seen in these boundary conditions.

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