Stress-strain behaviour of railway ballast under static loading using Finite element Method

Indramohan[1], Anand Singh[2],Pankaj Goswami[3]

Abstract-In railway engineering, finite element method is used to analyse the behaviour of railway track. This method is valuable to determine the important parameter of track at static and dynamic loading conditions. The ballast is one of the important part of track, so study of ballast is beneficial in case of degradation and deformation. This study is based on simulation of large scale triaxial machine of testing ballast and find some parameter like stress-strain behaviour at different confining pressure. Previous researcher has done 2D modelling of ballast in FEM software ANSYS, PLAXIS etc. In this study ABAQUS software was used for finite element analysis of ballast. Here, 3D model of ballast in triaxial loading condition is analysed at varying confining pressure and compared with experiment results. Elastic and plastic flow of ballast with varying confining pressure was examined. Drucker-Prager plasticity was used for ballast to get an approximate elasto-plastic flow.

KEYWORD: Ballast, FEM, ABAQUS, Static load, ANSYS, PLAXIS.

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1. INTRODUCTION

The Indian railway network is the fourth largest network in world and as compare to other source of transportation, railway provide better transportation facility at low cost. Most of the population in India belong to poor and middle income family, so they depends on railway only. So, to boost up infrastructure in railway to meet future demand and complete with other others country we need to thing about economy and new technology in railway engineering. Railway track consist of some important component like rail, rail pads, sleeper, ballast, sub-ballast and subgrade. The ballast is one of the important of track. The ballast is a layer of stones which is placed below and around sleeper to uniformly distribute the load from sleeper to sub ballast layer. It holds the sleepers in proper position. It also provides lateral and longitudinal stability to the track along with drainage facility [1]. Using Finite Element modelling, we can easily predict the stress-strain behaviour, vertical and lateral deformation of ballast in large scale triaxial machine.

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The main objective of this study to compare the ballast model with experiment set of triaxial testing on ballast.The validation of ballast model is also important in future to check weather effect of geosynthetics in the performance of ballast in FEM. So, Future plan should be the analysis of the ballast with Geogrid at mid depth of the model. In present scenario geogrid is mostly used in the railway track to decrease deformation and degradation of ballast and also to increase shearing strength. Functions of geosynthetics in railway track are separation, reinforcement, filtration, drainage, water proofing and protection. Many of the geotechnical experts are working on the geosynthetics. And in the present time different types of geosynthetics are available like geogrid, geotextile (woven and non-woven), geomembrane, geocells, etc.

2. LITERATURE REVIEW

Ballast is provides in the railway track to ease to transfer load from rail to subgrade. It is a free draining granular material and it contains medium to coarser gravel size aggregates from 10-60 mm with few cobble size particles [4]. The good quality of ballast should have particles with angularities, higher specific gravity, higher shear strength, toughness, and resistance to enduring, irregular surface and minimum hairline cracks [5].Large scale triaxial machine in laboratory can contain a ballast specimen of 150 mm diameter and 600 mm high. It consist of five main parts like triaxial chamber, axial

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loading unit, air pressure and water control unit, pore water pressure measurement system and volumetric change measurement device. The same setup of triaxial condition is modelled in this study. Only a ballast specimen with fully boundary conditions is analysed and compared with experimental result. In this machine test can be conducted as static and dynamic loading conditions. Many of the researchers has been done the analysis for shear strength of ballast at different confining pressure and they conclude that failure criteria of ballast is not perfectly plastic. The failure of ballast is called elasto-plastic failure. The elastic modulus (i.e. the tangent modulus at zero axial strain) from a monotonic triaxial test can be defined as the slope of the initial portion of the curve of deviator stress against axial strain [6].Peak friction angle of ballast is usually derived from triaxial test results of peak principal stress ratio, by rearranging the M-C failure criteria. The relationship of peak friction angle and peak deviator stress ration is shown in following relationship:

$\Phi p = \sin^{-1}\left(\frac{Qp}{2\sigma' 3+Qp}\right)$ ....(Equation 2.1)

Where, Φp=Peak friction angle

σ'1=Major Principal stress

σ'3=Minor Principal stress

The ratio of yield stress of material in compression and yield stress in tension is called as flow stress ratio. In case of ballast it is considered as isotropic material[10]. So, unity is used for this study. It is denoted by symbol 'K'.

3. FEM modelling in ABAQUS

For simulation of ballast in Large scale triaxial testing machine, a cylindrical model of height 600mm and 150mm diameter is placed between two circular plates of thickness 5mm, complete model is shown in Figure 3.1 . Partitions of the cell has done because of uniform distribution of mesh element. Property assignment is important for simulation problem. The failure criteria for ballast is used elasto-plastics as discussed earliar, where elastic property and Drucker-prager yielding is provided for ballast at different confining pressure. Next ,assembly of these all parts has done with the help of assembly tool in ABAQUS. Now, boundary conditions has provide for model, to exact as seen in experiment result. For static loading condition in strain controlled with rate of 0.07% strain has provided on the top surface. To surface of plate is free to move in downward direction but restrained in other and for bottom plate surface is fixed in all direction.

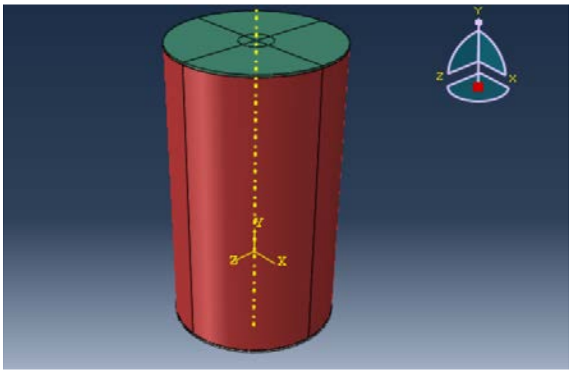

Figure 3.1 3D model of cylindrical triaxial machine in ABAQUS

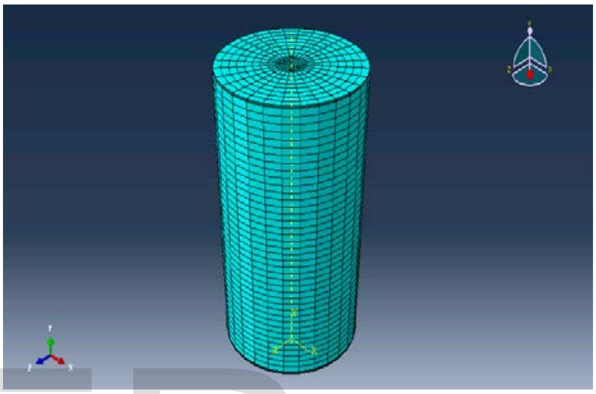

Figure 3.2 Meshing of model in ABAQUS

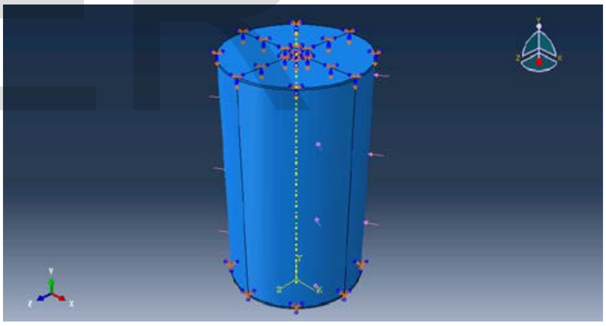

Figure 3.3 Loading and boundary condition of model in ABAQUS

Some the important parameter like elastic modulus, Poisson's ratio, friction angle, dilation angle and flow stress ratio.Elastic properties of ballast was calculated from experimental data by using initial elastic modulus equation[6]. As the confining pressure was increased elastic modulus of ballast also increased. To set an elastic modulus value for ballast weighted average was calculated as 29.41236 MPa. Same frictional angle also calculated using equation and according to range of confining pressure. Dilation angle varies see table. Using these all property FEM result of static load test on ballast is analysed at three ranges of confining pressure, low, medium and higher confining pressure.

4. RESULT AND DISCUSSION

In current study, stress-strain behaviour of ballast is shown at three ranges. Result in FEM software ABAQUS was adjusted according to variation in mesh size. So, one of the aim of study was to find the appropriate mesh size to get an approximate result. Figure 4.1 shows the number of elements versus lateral displacement of ballast at 1 kPa confining pressure. Here, sensitivity in the lateral displacement was shown with the increasing number of elements or mesh size. First result were checked on 35 mm mesh size where no. of elements are 1624.It was also shown in the figure that with increase in the element displacement increases consistently but less variation in the lateral displacement was between 5516 and 13200 elements. It means ABAQUS gives approximate result at fine mesh, so all the analysis were conducted at 15 mm global size mesh using 13200 number of elements.

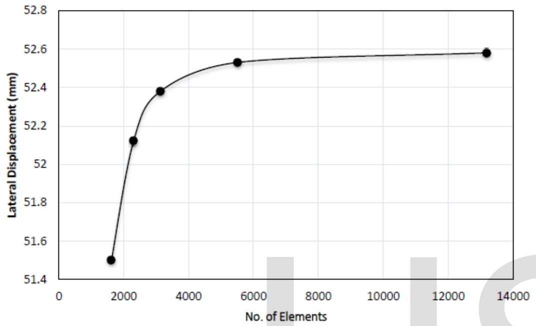

Figure 4.1 Mesh sensitivity check in ABAQUS

Elastic modulus of ballast is 30 MPa and friction angle 52° was used in simulation and for dilation angle value was 33°,23° and 7 °at low, medium and higher confining pressure respectively. Drucker-Prager hardening was used in this study as von-mises yielding criteria to get an approximate elastic-plastic flow of ballast mode.Firstly, stress-strain behaviour of ballast is analysed at lower confining pressure range in which confining pressure. Deviator Stress-Axial strain curve of ballast at lower confining pressure has been shown in Figure 3.2. Here, ballast model was analysed at three confining pressure 1 kPa, 8 kPa and 15 kPa. At low value of confining pressure of 1 kPa the maximum deviator stress reached in FEM analysis was around 0.148 MPa. But experimental results peak deviator stress value was 0.142 MPa. Finite element result was always slightly more than the experimental result, except that ABAQUS shows results with less percentage of error.

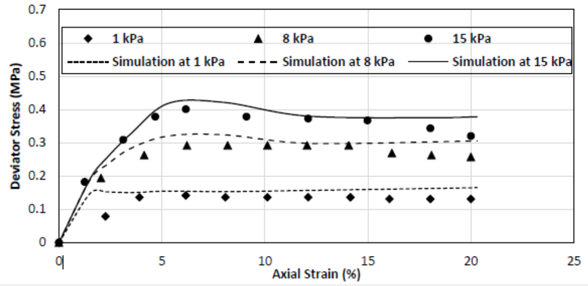

Figure 4.2 FEM result stress-strain curve for ballast with experimental result at low confining pressure range

In simulation ballast was considered as a solid element but in real case ballast sample is a well compacted stone particles as explained in chapter 2. But the elasto-plastic failure of ballast was fully seen in this analysis and also elasto-plastic flow of ballast was fitted with FEM result. As value of confining pressure increased, ballast behaviour also changed. In case of 8 kPa confining pressure, peak deviator stress was 0.32 MPa in FEM and in experiment result it was 0.292 MPa. Error in this case was 9%. Now, confining pressure was increased up to 15 kPa and plastic failure of ballast was analysed in the simulation. As compared to the experimental data, FEM software ABAQUS gave peak deviator stress of 0.418 MPa which was higher than the experimental results. Experimental result gave value of 0.400 MPa. In this case ABAQUS result showed less error of 4.5%.Deviator Stress-Axial strain curve of ballast at medium confining pressure has been shown Figure 4.3 Here, ballast model was analysed at three confining pressure 30 kPa, 60 kPa and 90 kPa. Elastic and plastic flow of ballast was fitted with FEM result. In medium range of confining pressure, test was first conducted at 30 kPa. Ballast shows complete failure curve as in the case of experiments the maximum peak was 0.540 MPa. In experimental result value was 0.498 MPa. The error in simulation was 8.4% for 30 kPa confining pressure.

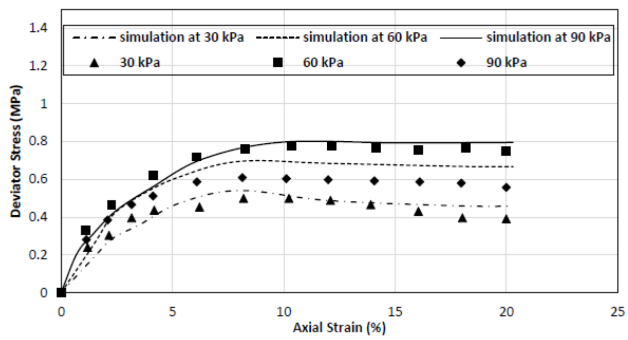

Figure 4.3 FEM result stress-strain curve for ballast with experimental result at medium confining pressure range

Now, Confining pressure was increased up to 60 kPa and stress-strain behaviour of ballast in FEM was similar in case of experiment. This time maximum deviator stress reached to 0.694 MPa, which was higher than experimental value of 0.609 MPa. Error in simulation was 13.9%. Again confining pressure was increased up to 90 kPa, which showed deviator stress of 0.794 MPa and the experimental result peak was 0.758 MPa. Elasto-plastic flow of ballast matched with experimental result and there was 2.45% error in peak deviator stress value.Deviator Stress-Axial strain curve of ballast at higher confining pressure has been shown in Figure 4.4 Here, ballast model was tested at confining pressure 120 kPa and 240 kPa. Elastic and plastic flow of ballast was fitted with FEM result. Behaviour of ballast in FEM analysis was quite good at 120 kPa. Maximum deviator stress value was 0.819 MPa and in case of experiment it was 0.775 MPa. At maximum confining pressure of 240 kPa, stress-strain behaviour of ballast was not fully matched with the experimental result but the peak deviator stress of the simulation was similar to that of the experiment. Maximum deviator stress was 1.3 MPa in FEM and in experiment it was 1.288 MPa.

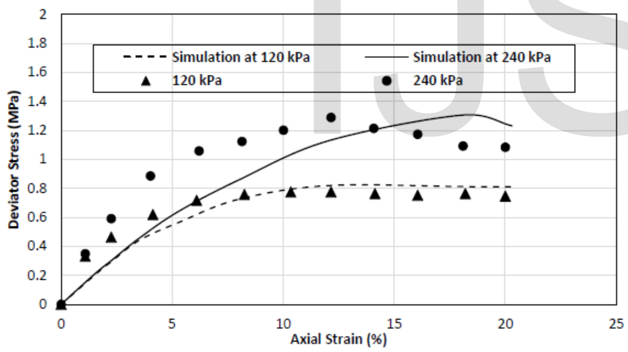

Figure 4.4 FEM result stress-strain curve for ballast at higher confining pressure range

5. CONCLUSION

FEM simulation of ballast sample in the cylindrical triaxial testing machine was completed using ABAQUS. Mesh sensitivity study is most important in case of finite element method because to get approximate result at particular fine mesh and decease time is essential. Analysis of ballast in strain controlled static loading condition was examined at low, medium and higher confining pressure. Stress-strain behaviour of ballast at elasto-plastic failure curve fully matched with the simulation result up to 120 kPa. At higher confining pressure, elasto-plastic curve, did not fully match, but an optimum peak of deviator stress was observed. After that peak, lateral displacement at different confining pressure was analysed. It possible to analyse behaviour of ballast and all railway track component in the FEM software at different loading conditions. Most important for future study in this area is to see the behaviour of ballast with geogrid and study of deformed shape of ballast specimen in large scale triaxial machine.The bonding of geogrid and ballast play important role to decide shearing strength and lateral displacement of ballast sample.

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