Finite elements model of a rotating half-bridge belonging to a circular settling tank

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Abstract. A circular settling tank is an open reservoir used for the gravitational separation of the sludge and of the clarified water which is discharged in the launder which is mounted at the periphery of the basin. The extraction of the sludge is done by the use of a rotating half-bridge which sweeps the sludge, vacuums it using a system of scrapping blades and suction pipes, collects it in some local sludge chambers and pour it in a central collecting tank. The rotating half-bridge is a complex structure under a complex system of loads, therefore advanced instruments of investigation are required to assess the state of strains and stresses in this structure. Until now an analytical model was developed based on the hypotheses specific to the strength of materials academic discipline. The numerical models presented in the paper use the finite element method to determine the displacements of the main beam loaded by the weight of the structure and by the Archimedes' forces. The results of the models developed so far are conclusive for the future directions of research which aims a higher degree of accuracy of the models and of the according research methodology.

1. Introduction

The half-bridge of a settling tank is a complex structure under a complex state of loads. The investigation of complex phenomena require customized research instruments and the creation of computer based hybrid models whose components use analytical, numerical and experimental methods [1] [2]. Until now, studies regarding the structure under investigation were developed, being created an analytic model [3], and being conceived experimental research methods [4]. One can notice that the theoretical methods, i.e. the analytical and the numerical models of a structure use the same classes of input information: the sub-model of the geometry, the sub-model of the material, the sub-model of the supports and the sub-model of the loads. It results that the same information may be used in both models, the finite element model and the computer based analytical model. Some of the weak points of the analytical studies are: lack of high accuracy because they are based on 'classic' hypotheses conceived in an age of technological development when the calculation instrument was unevolved, and the modelled phenomena may be at most of medium complexity. If an implementation of the analytical model is done the lack of flexibility and volume of calculi are not important weak points anymore. In addition, information may be easily transferred to the other types of studies. However, synchronous with our nowadays computing instruments are the numerical methods, especially the finite element method that is flexible and reliable for the experienced structural analysts. In the

following sections is presented a study that uses the finite element method in order to create the numerical model of the half-bridge.

2. Problem formulation

The theoretical solutions, i.e. analytical and numerical models of the structures are based on the following models: the geometric model of the structure, the model of the material, the model of the loads and the model of the supports.

In this case the strength element of the structure is the main beam, therefore according to its shape the geometric model must consider beam components.

The structure is manufactured using steel and it is loaded in the linear-elastic range of stresses. The model of the material is accordingly conceived as linear-elastic.

2.1. Model of the loads

The strength beam of the rotating bridge, figure 1, has a tubular shape and it is loaded by:
• weight forces produced by the scrapping system of blades - 3, suction pipes – 4, local sludge collecting chamber - 5 and of the sludge in the horizontal sludge transporting pipes – 7;
• forces produced by the walkway – 11;
• buoyant forces produced by the floating barrels according to Archimedes' principle – 6;
• equally distributed force produced by the weight of the main bridge.
These loads are producing bending and torsion of the main beam.

Figure 1. Components of the rotating half-bridge.

Other types of loads will be considered in a more accurate version of the model that will also consider the hydrodynamic forces resulted from a fluid-structure interaction complex model.

2.2. Model of the supports

The outer end of the rotating half-bridge is supported on a wheel, therefore it is free to translate along the X axis and it is free to rotate around the X and Y axes, figure 2. The central support is a vertical bearing which allows the end of the bar to rotate around the Y axis. Because of the vertical forces along the side brackets, the main beam of the half-bridge is loaded by a twisting moment, being necessary to block the rotation around the X axis. The blocked degrees of freedom are necessary for the overall balance, otherwise the structure becomes a mechanism.

3. Discussion and results

We remind some basic rules in the Femap application because we must define the geometry accordingly. Femap uses 'points' and 'curves' to define the geometrical model, while the discretization uses 'nodes' and 'elements'. The 'curve' entity type also includes line segments defined by two end 'points'. Using the 'points' and 'curves' there may be automatically generated the discretization of the structure. Taking into account these concepts, we considered a set of points along the main beam of the half-bridge and along the side brackets that were used:

- to define the line segments;
- to precisely specify where the forces are located;
- to connect the geometrical elements of the structure.
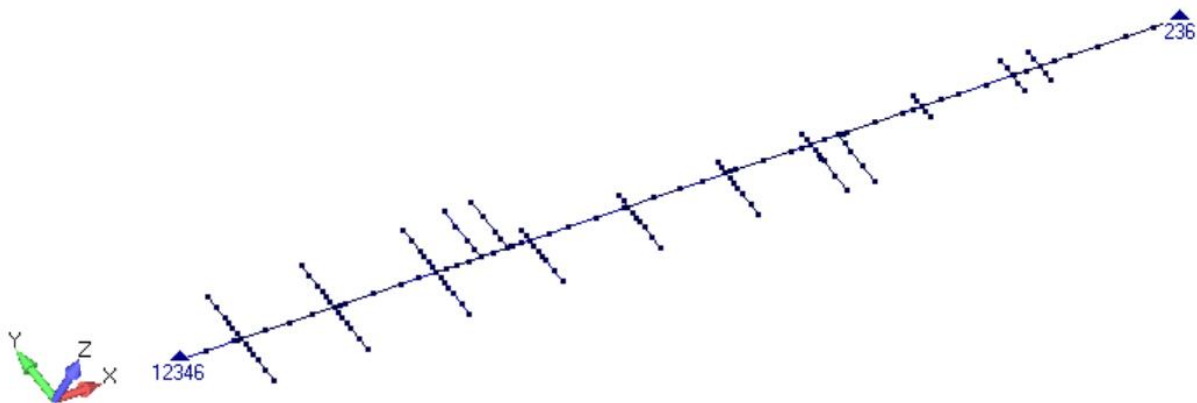
Figure 2. Geometry of the structure: points and lines and the boundary conditions.

These aforementioned points along the structure may be considered either to define the geometry, or to define the discretization. We preferred to use these points to define the geometry, in order to have more flexibility of the structures' modelling.
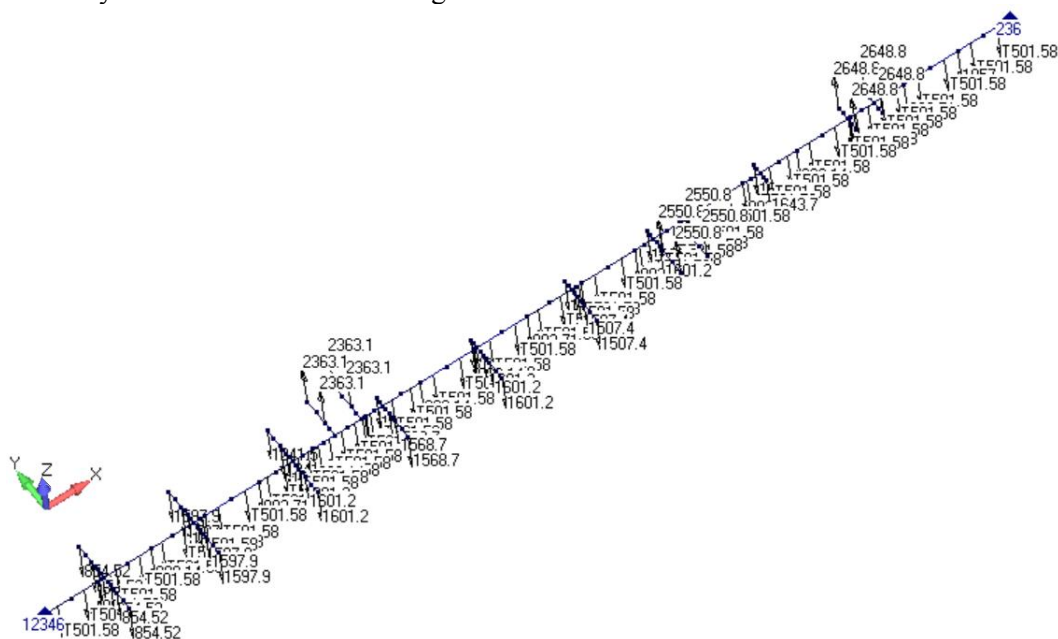

Figure 3. Loads applied onto the structure.

Once the geometry is defined using the 'points' and the 'curves', all the other information (loads, constraints) may be defined with respect to these entities. Moreover, the structure may be discretized in several ways using the same basic information that is linked to the geometry of the structure.

The high complexity of the structures' geometry required the automatic data processing, all the details of the geometry being analytically modelled.

The dimensions of the geometry were thoroughly and accurately considered in order to compute the weights of the structure and of the sludge. There were also computed the buoyant forces produced by the floating barrels, in figure 3 being represented upwards.

The properties of the beam elements were defined for two types of cross sections. The main beam of the half-bridge has a tubular shape, therefore we selected the standard shape 'Circular Tube' and we set the appropriate dimensions. Regarding the brackets, we defined the cross section using the standard 'Angle (L) Section' type. Being a non-symmetrical cross section we also tested the option regarding the shear center effect and other shapes, such as a rectangular shape.
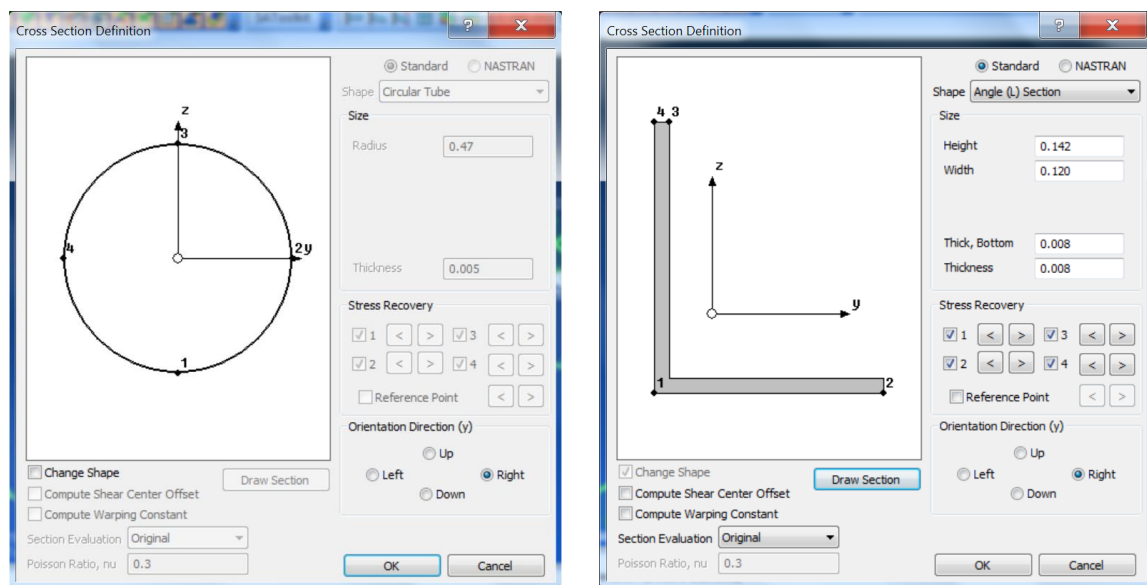

Figure 4. Definition of the cross sections of the beam elements.

During the execution of the analysis it has been reported the warning "Verify that the degrees of freedom are not part of a mechanism and that elements do not have excessive stiffness." This warning made us rethink the numerical model taking into account that, in general, we have two types of problems which cannot be mixed. The first one regards the strength of the entire structure and the second one is focused on the behavior of some components of the structure, i.e. local resistance problems. We identified two ways to solve the problem.

The easiest way was to replace the thin sections of the brackets with some larger stiffness sections which may be comparable with the tubular section of the half-bridge. In this way the results consisting of free body diagrams and deflection may be applied only for the main bridge. For the brackets there may be considered only the free body diagrams, not the deflected shape. Moreover, the reduction of the system of forces applied on the brackets with respect to the longitudinal axis of the tubular bridge may not be done, because the model still takes into account the twisting moments produced by them. The results are presented in figures 5, 6, 7 and 8.
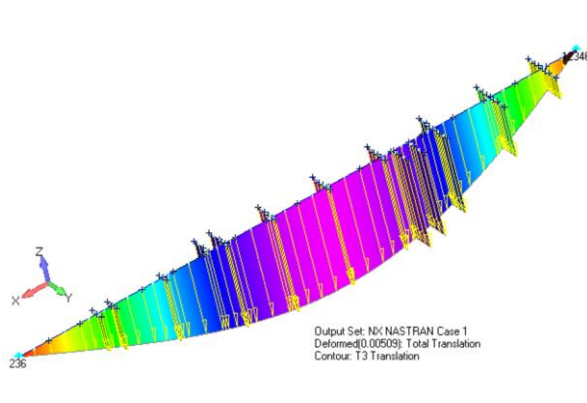
Figure 5. Displaced shape of the structure.
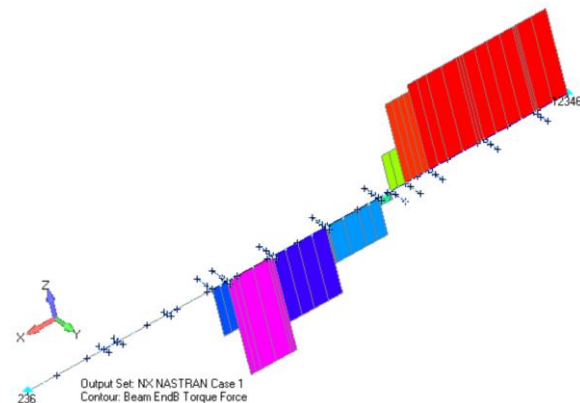
Figure 6. Twisting moment diagram.
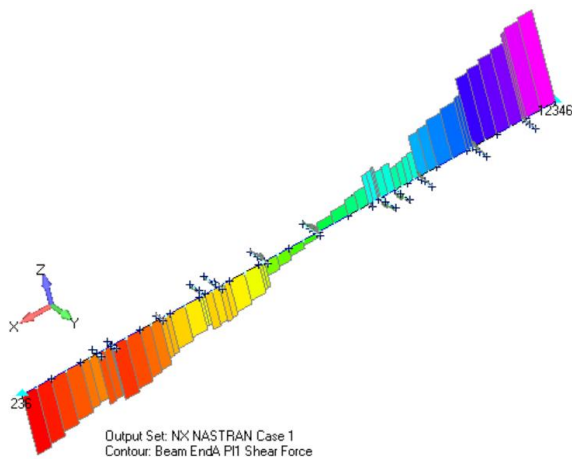
Figure 7. Shear forces diagram.
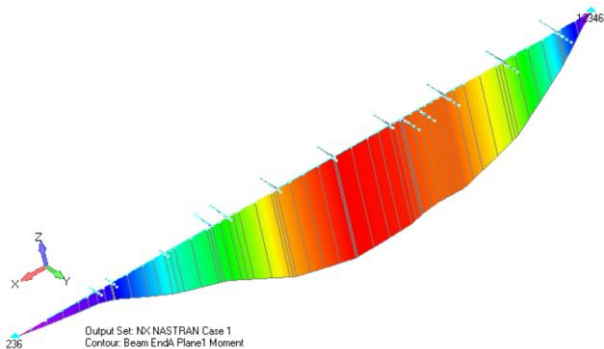
Figure 8. Bending moment diagram.

We have also developed a new model that considers only the flexure of the half-beam which has a circular tube section. In this way the brackets are not considered into the model, therefore the forces on the brackets are reduced in the point having the same X coordinate, for which Y=0, i.e. it is located on the axis of the half-bridge.
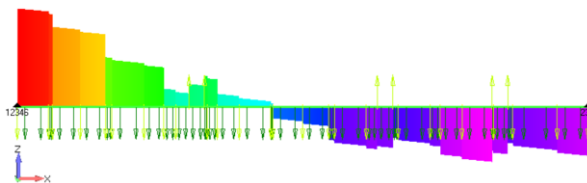
Figure 9. Shear forces diagram for the model loaded only by flexural loads.
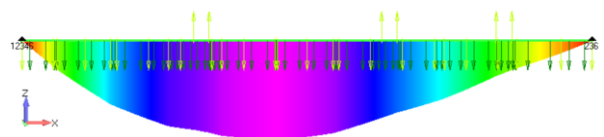
Figure 10. Bending moment diagram for the model loaded only by the flexural loads.

The results of the finite element model loaded only by flexural loads, i.e. external forces and equally distributed forces are presented in the previous figures.

4. Conclusions

The results of the model show a low level of stresses, which is important because the half-bridge is designed to work for decades and the fatigue phenomenon may be less severe.

The numerical models developed may be refined in order to take into account additional loads, such as the fluid-structure interaction.

Using these numerical models we can study various scenarios. In one of the scenarios we may consider some broken floating barrels which are annulling the Archimedes' forces that can be noticed in figure 3 having an upward direction. Other scenario may consider the additional loads produced by the weight of the people standing on the walkway on the half bridge. In these case studies, apart from the strength related problems we must evaluate the vertical displacement of the half-bridge. If large values of the vertical deflections are recorded, the scrapping system of blades may press on the concrete floor of the settling tank, situation which may affect the normal running conditions of the equipment.

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