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FEM MODELING OF SPATIAL STRUCTURAL SYSTEMS IN EVALUATION OF THE REAL STRUCTURAL PERFORMANCES

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Abstract. *The paper is a review of enhanced concept of CASA (Computer Aided Structural Analysis) software application in FEM modeling of spatial structural systems of bridges, buildings, industrial facilities, machine devices, etc. in evaluation procedures of real structural performances. Contrary to everyday engineering design circumstances, which comprehend, primarily, respect of technical regulations, FEM modeling in case of structural evaluation, needs, in some sense, alternative type of creativity. Chosen examples could be illustrative for this attitude.*

Key words: *FEM modeling, performance evaluation, test-by-load, CASA software.*

1. INTRODUCTION

Technical codes which regulate subjects in the structural design field (in civil engineering, especially) are based on the rules which are related to achievement of structures which have bearing capacity, stability, serviceability and durability. Mentioned conditions are often associated with economic i.e. financial as well as aesthetic issues.

Real behavior of structures (i.e. real response under action) is the second order fact in many cases of standard design procedures and numerical analyses. Such pragmatic approach is legitimate because of actual circumstances in everyday design office practice.

Structural evaluation (test by load or other evaluation procedures) are necessary steps in final assessment of capability structural systems for some type of objects. Criterions and needs which structures have to fulfill before their full service are described by the technical regulations of almost all countries. But there are not details about modeling of real response-under-action in almost all regulation documents. This issue, probably, does not have such importance in case of standard design, but for the prediction of a response

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caused by test load or in cases of some specific structural evaluation procedures it is necessary to respect some modeling principles and rules.

Next chapters are aided to emphasize of importance of correct application of FEM technology according to these principles and rules with special attention paid to spatial structural systems which are the most illustrative example of necessity of advanced approach in modeling.

2. BASIC FEM MODELING PRINCIPLES IN STRUCTURAL EVALUATION

FEM model for the structural evaluation purposes should be completely determined by:

- structural topology and geometry,
- values, distributions and rules of change of stiffness, mass and damping parameters for structural elements, parts and structural system in a whole,
- definition of real behavior of used materials under loading/reloading/unloading conditions,
- definition of a real behavior of supports and connections (see [4], [7]) and
- determination and real modeling of actions (i.e. loads).

Chances of making of errors in structural topology modeling (discretization errors) are negligible, because they are simple evident even for non-experienced designer/evaluator. Graphically oriented preprocessor implemented in CASA FEM software (good example is [1]) offers great help in geometry modeling what is presented in [8]-[10]. But it is necessary to emphasize that common approach in modeling of geometry could be, in some cases, source of problems (false structural response, described in [5]), which will be illustrated by examples.

Stiffness and mass parameters are not problem to calculate and include in any FEM model, but definition of damping values and distribution is complex task. Additionally, approximation errors caused by the choice of wrong type of FE are more probable (see in [2], [3], [6]). This fact will be illustrated by the examples in the next chapter.

Maybe the most creative use of FEM technology should be dedicated on modeling of supports and connections, i.e. boundary and interface conditions. Challenges and solutions will be shown by few examples.

Actions (loads or various influences) can be simply modeled especially in case of monotonous static loading without reloading/unloading issues. Besides, designers make mistakes in some cases of very well defined actions. Particular problem are loads which cause vibrational structural behavior and inertial forces which are very complex to apply in test-by-load as well as to model in numerical evaluation procedures.

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3. FEM MODELING EXAMPLES OF EVALUATED STRUCTURES

Goal of the structural performance evaluation is determination of real amount of structural bearing capacity, stability, safety and serviceability. Technical regulations are based on numerous assumptions which are required because of increasing of efficiency of design process, safety of designed structures and level of designer's knowledge and proficiency. This is main reason because simplified FEM models (used regards to the regulations) are inadequate for the evaluation of real structural performances. Following examples could be illustrative in the sense of perception of importance of very sophisticated approach in FEM modeling of structures which are object of mentioned evaluation.

First group are cases in which geometry modeling (although it is performed in reasonable way) strongly impacts to the distribution of internal forces. Typical representative of this group is example of silo cylinder structure modeled by shell FEs, Fig. 1.

Flexural moments (in "hoop" direction) occur in case of uniformly distributed external load even for properly big number of FEs trough circumferences of the silo cylinder. According to the well-known analytical solution ("hoop" stress formula for the thin walled cylinders) there are only membrane stresses for this type of external load. These nonexistent flexural moments (and corresponding stresses) could be on the "safe side" or on the "non-safe side", what is important, especially for the reinforced concrete structures (in the calculation of required amount of tensioned or compressed reinforcement). There are two possible solutions for this problem: enlargement of number of FEs in hoop direction ("brutal force" approach indeed) or correction of normal stresses in hoop direction regards to fact that there are no moments. The best solution is combination of mentioned approaches according to the real configuration of external forces on the silo's cylinder (pure uniform distributed circumferential load is rare or only theoretical case).

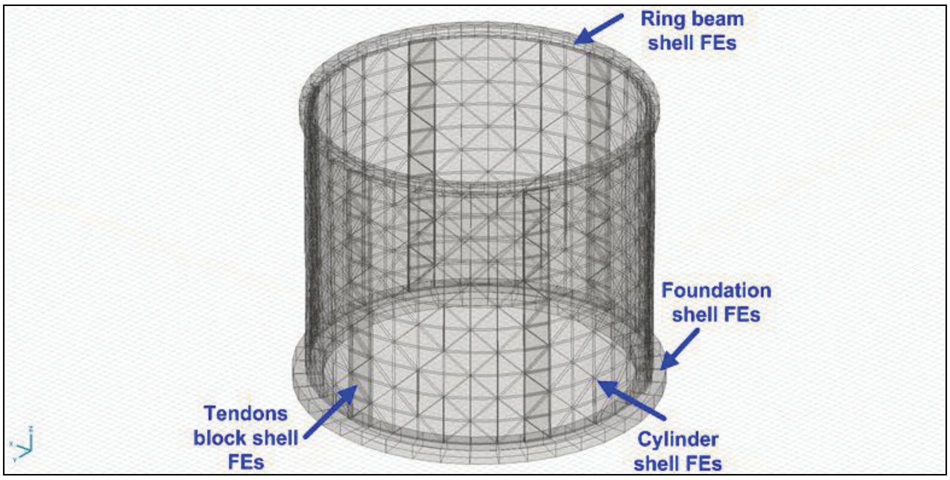

Fig. 1. Typical silo structure with ring beam foundation, cylinder shell and ring top beam

Same example could be helpful as an illustration of correct way for modeling of support and connections. Fig. 2 presents use of special "link" FEs for connections modeling.

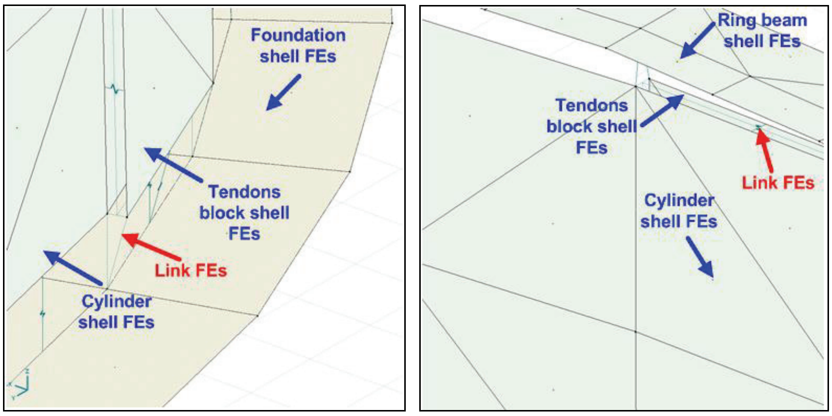

Fig. 2. Details of the connections in silo's FEM model

Special link elements are one-dimensional FEs with all six degree of freedom and corresponding stiffness parameters which make possible modeling of almost every type of connection. This fact emphasizes advances of such type of model as more real than simplified models which are used in initial design procedures.

Problems with modeling of some actions (loads) could be illustrated on this example, also. Usual approach for modeling of pretension by cables is replacement of cables influence by the equivalent uniform load, Fig 3 (left). Much better solution is consequent modeling of cables by cable or beam FEs which are connected with silo wall shell FEs by link FEs, Fig 3 (right). Only this way of modeling makes possible check of pretension force after action of the other loads.

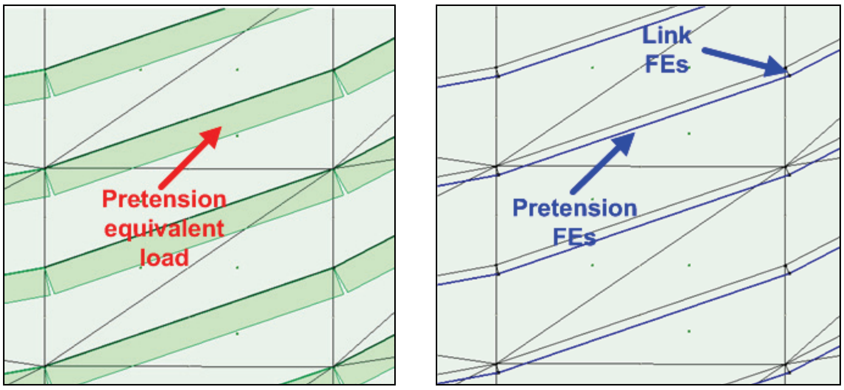

Fig. 3. Pretension modeled as equivalent loads (left) or by cable/beam FEs + link FEs (right)

Another type of modeling problems is caused by improper choice of FE type. Thin walled spatial structures need treatment by application of shell FEs, regardless of the dominant dimension in the structural topology. Fig. 4 shows FEM model one jib structure *which is a typical part of the waterway dredgers facilities.*

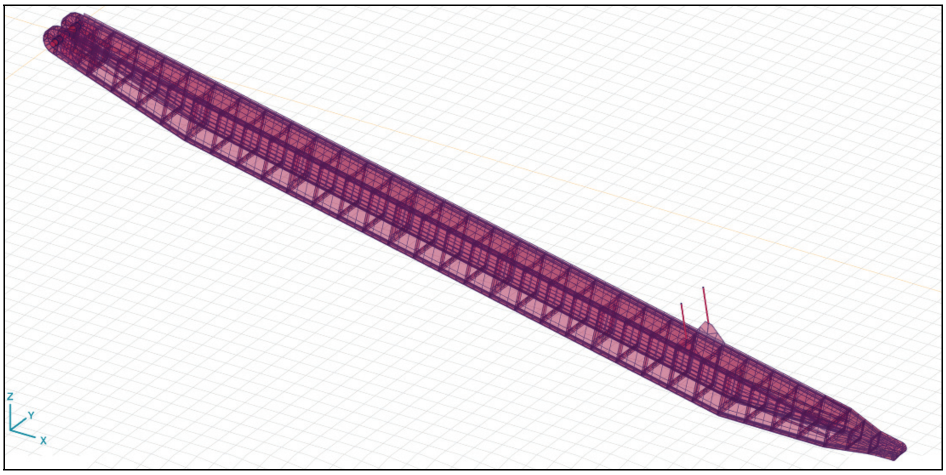

Fig. 4. FEM model of spatial jib structure

Complex structure of jib consists: lateral stiffeners of diverse type and dimensions and thin walled cover plates, as well as parts for supporting the jib on the deck of dredger, Fig. 5.

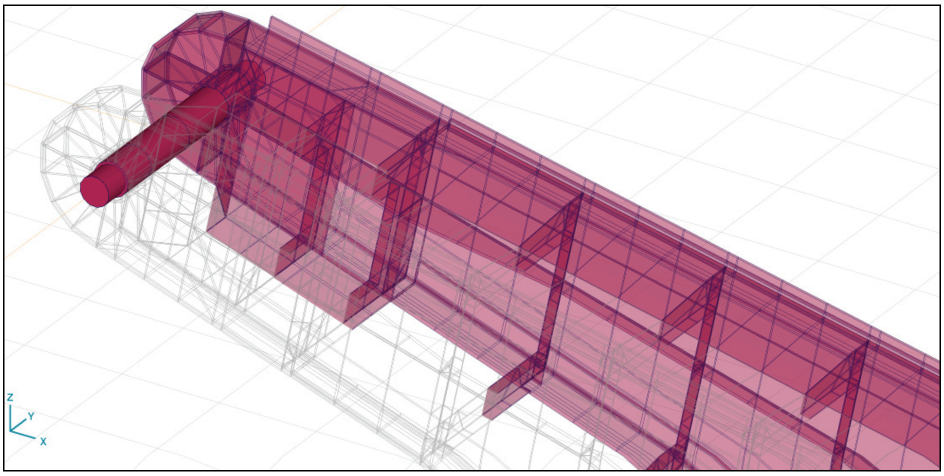

Fig. 5. Details of FEM model of spatial jib structure

A simple numerical test will illustrate the advantages of a model with 2D FE in relation to the 1D FE model. This and similar "benchmark tests" should become an essential part in the final FE model choice methodology.

The analysis is performed for the uniformly distributed load. Fig. 6 shows principal stresses and vertical displacements in characteristic points as well as the lowest natural frequencies for 1D (top) and 2D (bottom) models.

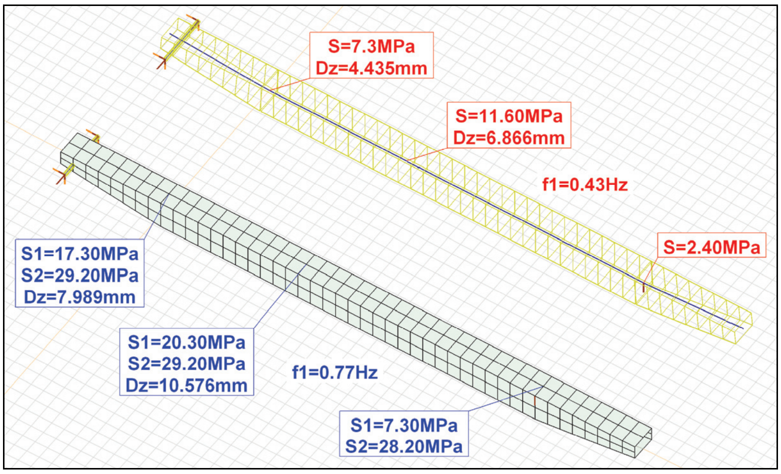

Fig. 6. 1D and 2D models: displacements, principal stresses and the lowest natural frequencies

1D model is formed from the beam FE (box shape 2400mm x1000mm cross-section, t=20mm) and in the topological sense it is completely identical to the 2D model with the rectangular shell (isoparametric, nine-node, heterosis) FE (thickness t=20mm). Boundary conditions are identical for both models and adjusted to the real jib's supports conditions.

It is evident that the principal stresses (S1 and S2) in the more accurate 2D model are 1.75 to 11.75 times greater than in a simpler 1D model. The case with the vertical displacements (Dz) is similar. Here the factors are from 1.54 to 1.80 more beneficial to the complex 2D model. Furthermore, the lowest natural frequency (f1) in a 1D model is almost 1.8 times lower than the same frequency in the 2D model.

This test shows very clearly that apparently similar models can obtain very diverse data about the structure, and sometimes also a very wrong impression about the bearing capacity, stability and serviceability, thus definitely confirming the demand for applying more complex models.

Modeling of connections is the critical phase here. The axle-jib connection is actually a cylindrical hinge allowing only the rotation around one axis. In Fig. 7 is a model of this hinge with the distribution of link FEs. Link FEs radially join a node of the axle's beam FE and attached nodes of the shell FEs of the jib hinge.

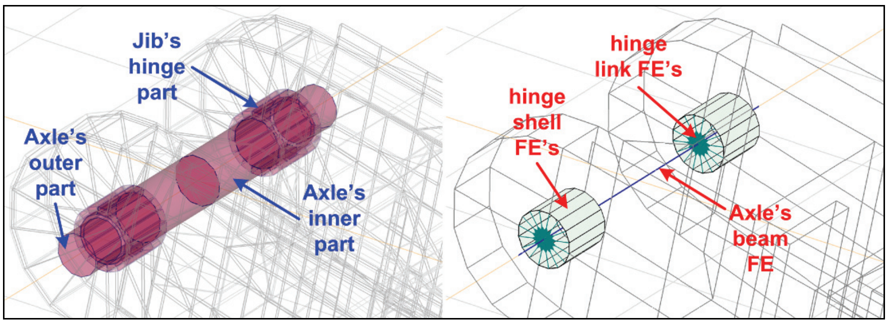

Fig. 7. Modeling the hinged support by link FE

Similar case is any eccentricity in connections in the thin-walled cover or in the stiffeners, Fig. 8. Here, all six stiffness parameters of link FEs have a non-zero value that simulates a rigid welded eccentric connection. In some cases there is a necessity for such model configuration, especially if there is a large membrane forces.

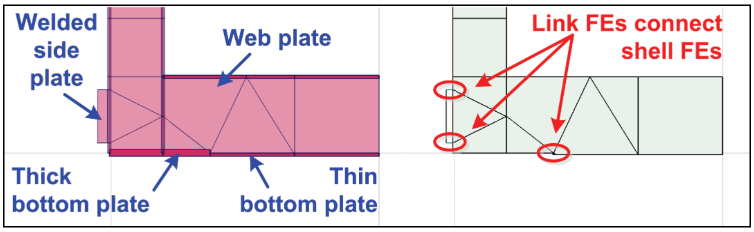

Fig. 8. Link FEs for eccentricity connections

In this sense, following examples are also illustrative. Fig. 9 shows FEM model of bridge which tested by load, with model details in the Fig. 10.

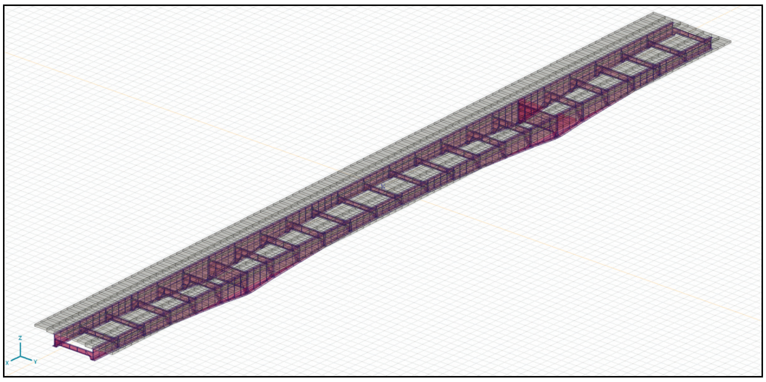

Fig. 9. FEM model for the bridge in test-by-load procedure

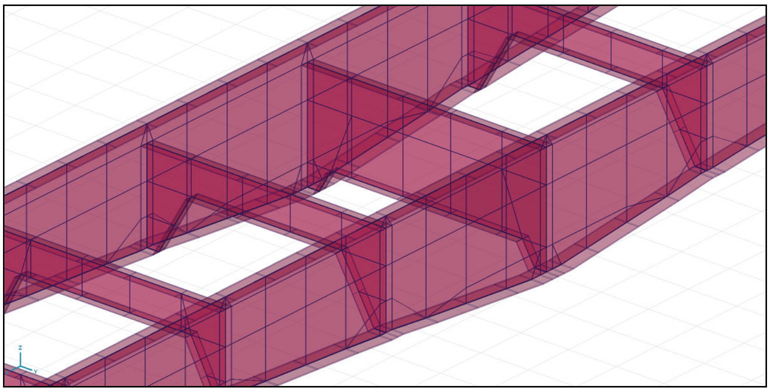

Fig. 10. FEM model details for the bridge in test-by-load procedure

Composite structure of the bridge (steel main girder + concrete plate) showed torsional flexibility in the test-by-load, what is fully verified by presented FEM model, with first torsional natural shape, Fig. 11. Unfortunately, basic design analysis, based on one simplified model (built by 1D FEs), had slightly different results.

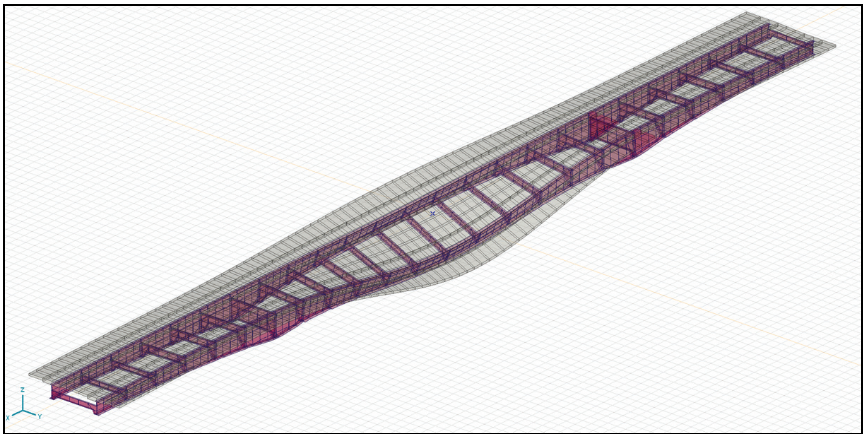

Fig. 11. First (torsional) natural shape of the FEM model of the tested bridge

Displacements of structural system of one concrete bridge (pretensioned girders + reinforced plate) which is modeled according to rules which should be used in the modeling of such important structures is given on the Fig. 12. Initial design analysis, based on one simplified model (built by 1D FEs), showed noticeably bigger displacements and, in this sense, could be considered as "over dimensioned".

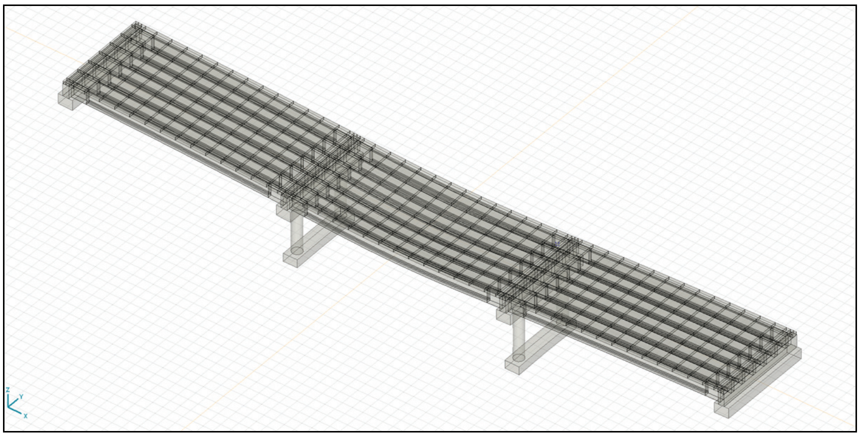

Fig. 12. Bridge FEM model displacements for the most unfavorable test load position

Finally, the last example is, maybe, the most illustrative for the approach preferred here: the substantially important structures need adequate FEM modeling treatment, especially in the case of evaluation procedures. Fig. 13-14 show FEM model which was omitted as the main model for test-by-load evaluation of very well-known bridge, reconstructed after the destruction in bombing campaign.

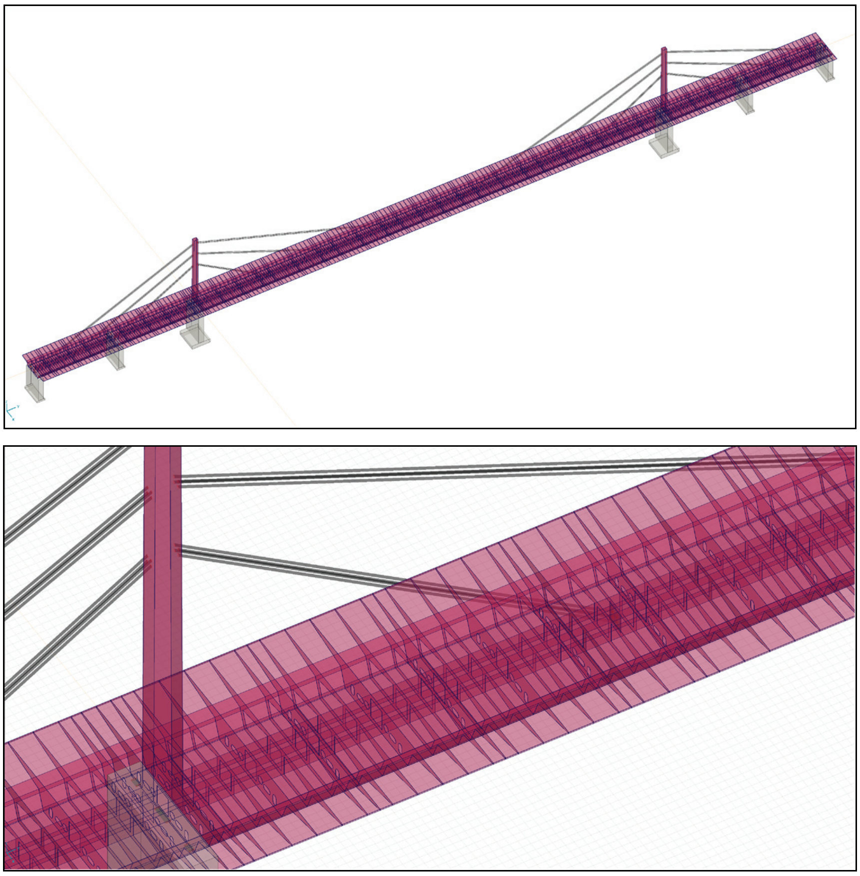

Fig. 13. Adequate FEM model for the bridge with an "out-of-categorization" importance

CONCLUSIONS AND FINAL REMARKS

Given examples show that FEM modeling performed by evaluator of structures and designer are different in a conceptual sense: in a whole or in the substantial details. Resolution of this unfavorable situation could be achieved by the changes in the field of engineering education as well as in the enhancements of the technical regulations.

"Old fashioned" educational curriculums, for the structural analysis subjects especially, must be innovated. Achievement of the "encyclopedia" knowledge, by studying of many methods for analysis, possibly provides "good old" education, but it takes away attention of students. Such knowledge is not necessary if in the analysis the CASA software is applied in competent manner.

Conceptual "out-of-date" state of the technical regulations brings the CASA software advanced users into a situation that software is used with difficulties. Regulations should be harmonized with the most important heritage of the FEM technology: elimination of manual operations and making more time for the creative design.

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MKE MODELIRANJE PROSTORNIH KONSTRUKCIJSKIH SISTEMA U PROVERI REALNIH KONSTRUKCIJSKIH PERFORMANSI

Dušan Kovačević, Slobodan Ranković

Rad je prikaz naprednog koncepta primene softvera za računarsku analizu konstrukcija u MKE modeliranju prostornih konstrukcija mostova, zgrada, industrijskih postrojenja, mašina, itd. u postupcima provere performansi konstrukcijskih sistema. Za razliku od svakodnevne projektantske prakse, koja se zasniva na poštoivanju tehničke regulative, MKE modeliranje u slučajevima provere stvarnih performansi konstrukcija, zahteva, u izvesnom smislu, alternativni kreativni pristup. Izabrani primeri mogli bi da budu ilustracija ovog stava.

Ključne reči: *MKE modeliranje, provera performansi, probno opterećenje, CASA softver*