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COMPARATIVE STUDY RELATED TO FAILURE FORCE AND FAILURE MECHANISM BETWEEN REAL LIFE TEST AND 3-D FEM MODEL ON A HIGHWAY BEAM

BY

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Abstract. This document aims to presents the comparison in terms of failure force and failure mechanism between a real life experiment conducted in 2008 on a highway prestressed and precasted box beam subjected to concentrated loads and loaded until failure in 6 load cicles and a 3-D finite element model prestressed, loaded and constrained in the exact same manner. The reason for a 3-D finite element model was to a better observing of the behavior of stress, strain and crack distribution in the beam and to calibrate the model in order to make a parametric study in the future, varying different aspects: load application, section thickness, prestress, etc. The results of this study may provide important informations, considering that our country has a huge potential for implementation of prestressed box girders due to the urgent need to achieve a modern and adequate transport infrastructure. The validity of the proposed model is demonstrated as follows by comparison with experimental results obtained by INCERC. This paper deals with the largest destructive test, ever performed in Romania on a prefabricated bridge box girder.

Key words: prestressing; precast box beam; failure; 3-D finite element model (FEM).

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1. Introduction

In recent years, precast, prestressed concrete beams have been produced for highways and bridges with significantly higher spans than in the past (Stratford *et al.*, 1999). For example, in UK, the bridges standards established a maximum span lenght of 40 m while in Canada spans of up to 55 m can be erected. If spans get longer and beams more slender, such beams are liable to different phenomens that can appear, such as: stability problems, short and long term deflections, deformations depending on the postion of the loading, the prestressing force affecting the behaviour of the beam etc., which are directly related to the beam section: T, I, Box, Y, Super Y (SY).The correct section beam chosen depends on the factors that affect the general and local behavior of the girder. All these aspects are given in specific standards for each country. A box girder normally comprises of prestressed concrete, structural steel or steel reinforced concrete.

The distructive test carried from this paper had the purpose to study the behavior, the quality and the performance of 37.10 m precast, prestressed highway beam. It should be noted that with the help of the 3-D finite element softwares existing on market, after calibrating the FEM model, a parametric study can be made without the use of real life tests in order to further optimize the long span precasted beams.

2. Experimental Work

The destructive test took place in September15-18, 2008, on Bechtel International Inc. Reno-Nevada, Cluj-Napoca, in accordance with the design completed by Iptana SA Bucharest. Work site at a temperature of 11ºC and relative humidity of 80%. Test setup static scheme is presented bellow. Figs. 1 and 2 present aspects related to the test.

The total height of the transversal sections is 2.45 m, with the height of the U girder of 2.20 m. As we can see below, bottom flange thickness varies along the beam span.

Load was applied in load cycles as follows (Păstrav, 2010):

a) (nondestructive) the four concentrated loads were applied in two different loading-unloading cycles corresponding to regular service load (C1 and C2), the force having the following load steps: 110 kN, 148 kN, 170 kN, 192 kN, 213 kN, 235 kN and 256 kN, the unloading was made until 62.5 kN (self weight of the loading device);

b) (destructive) the four concentrated loads were applied in one loading-unloading cycle corresponding to Cracking Limit State (C3), the force having the following load steps: 302 kN, 346 kN, 438 kN, 453 kN, 468 kN and 483 kN, the unloading was made in two steps until 62.5 kN (self weight of the loading device); two more cycles followed (C4 and C5), the force had similar steps as cycle C3 and then the load steps were: 535 kN, 635 kN, 684 kN and 736 kN, the unloading after each cycle was made in two steps until 62.5 kN (self weight of the loading device); the last loading cycle (C6) was made until failure (*P* = = 1,533 kN failure force corresponding to crack width of 1.0 mm), the force had similar load steps as C4 and C5 and then the load steps were increased with a value of 101 kN at each load step.

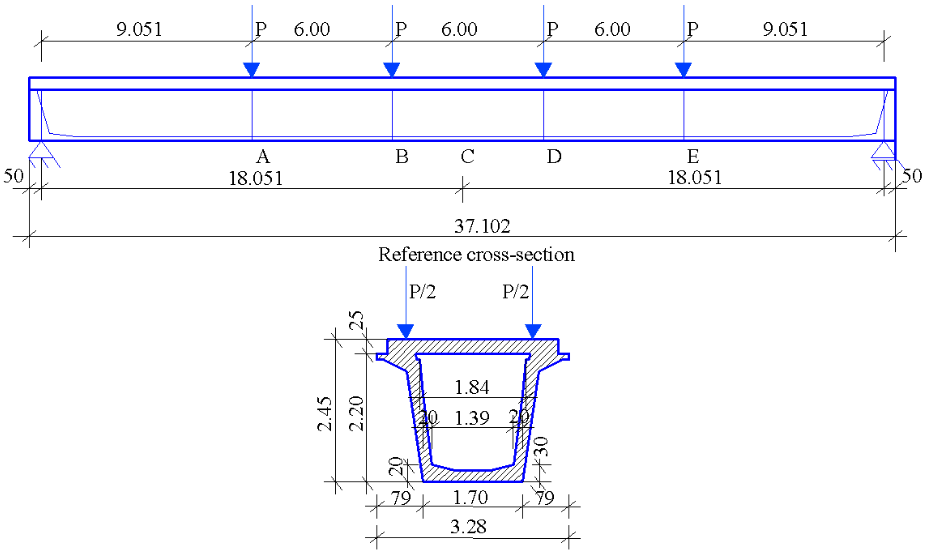

Fig. 1 – Static Scheme (Contract 1167/2008).

During the test all parameters presented in STAS 12313-85 were measured.

Fig. 2 – The 37.10 m Box Beam on the stand (Mircea *et al*., 2009).

3. Finite Element Model

The numerical simulation (FEM) was made by using a 3-D finite element method software TNO DIANA. With the help of such a model, parametric studies can be carried out later without the use of destructive methods such as real life experiments. With the help of finite element softwares such as Diana, companies and research centers can cary out a vast number of experiments on screen at zero expense and without producing any waste material lost in real life experiments. Test setup static scheme is presented bellow. Figs. 3 and 4 present aspects related to the FEM analysis.

For material models we used the following:

a) for prestressed beam we used concrete class C50 with the characteristics given in the Model Code 2010;

b) for toping we use concrete class C50 with the characteristics given in the Model Code 2010;

c) for passive reinforcement we used von Misses material model with the modulus of elasticity of 210,000 MPa and yield value of 500 MPa;

d) for the active reinforcement (prestressed tendons) we used von Misses material model with the modulus of elasticity of 195,000 MPa and yield value of 1,860 MPa.

The model was constructed as an identic replicate of the real life experiment and the creation stages are presented in Fig. 3.

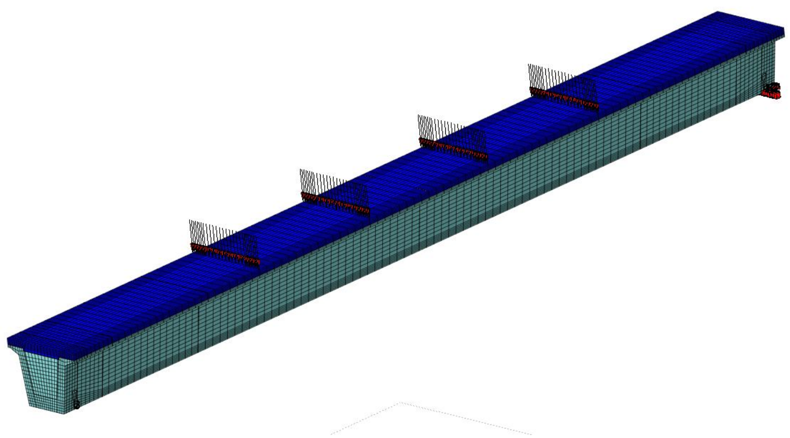

Fig. 3– Element geometry and mesh, concentrated forces and constrains.

Reinforcement were modeled as unidimensional elements (line or wire) having perfect bond with the concrete matrix.

For this model a nonlinear analysis was used. There are several methods to be used in order to solve this: load controlled methods (Newton-Raphson) are well known, but this method fails near the limit point so we avoided this method and we used the arc-length method (Riks 1972-1979) and Wempner (1971). This method is able to solve snap-through or snap-back behaviors and to identify the precise moment of failure.

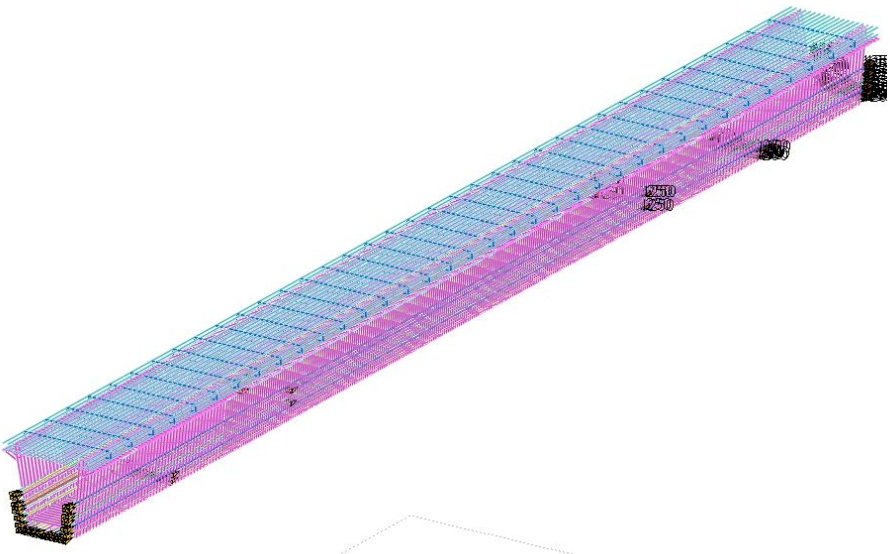

Fig. 4 – Reinforcement layout and prestress force application on tendons.

Two phase analysis was used in order to simulate the prestress in phase one and loading in phase two.

The analysis consisted in 20 different load steps, the last load recorded being 1,690 kN (without calibration). In terms of failure load, the difference was of approximate 10% when comparing the failure load recorded in reality and the failure load recorded in the 3D FEM model.

Results from the FEM analysis are presented below:

a) Von Misses stress distribution after prestress phase shows clear a concentration of efforts in the tendon areas due to transfer of prestressing force (Fig. 5).

b) Crack distribution also show a big compressive force at transfer leading to cracks in the concrete matrix in the vicinity of the tendons (Fig. 6).

c) By studying the stress distribution at last recorded step we can identify flexure as being responsible for failure of the beam (Fig. 7).

d) Crack distribution at last recorded step also help us to identify flexure as being responsible for failure of the beam (Fig. 8).

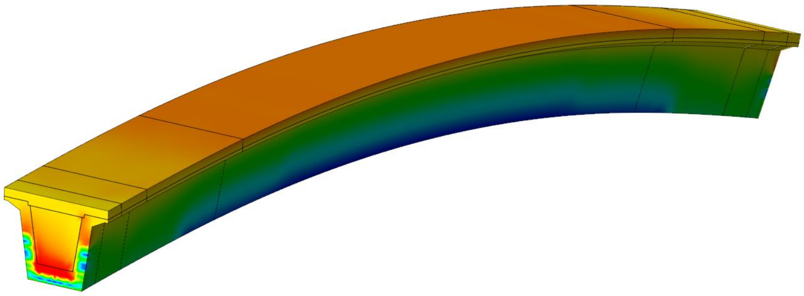

Fig. 5 – Stress distribution after prestress phase

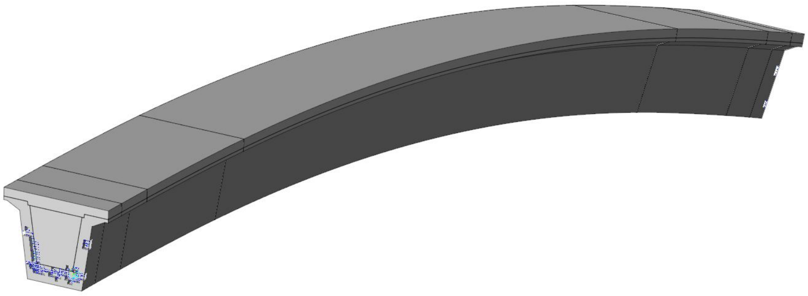

Fig. 6 – Crack distribution after prestress phase.

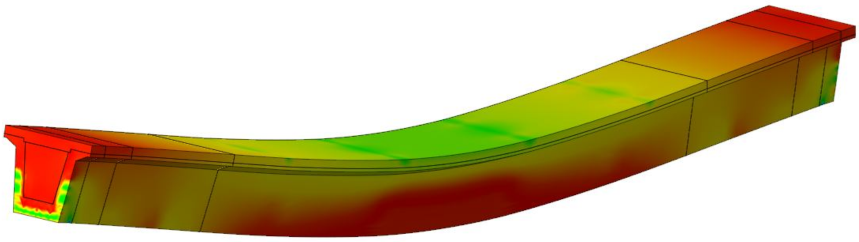

Fig. 7 – Stress distribution at failure.

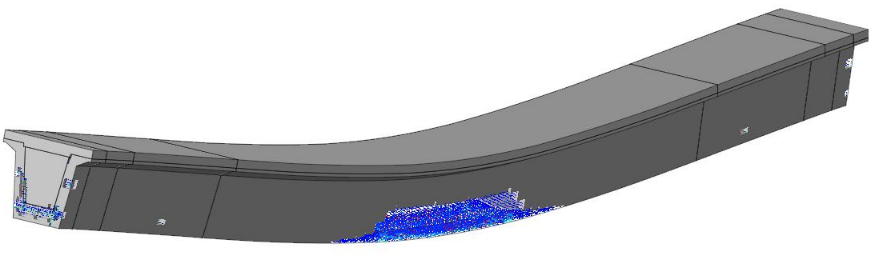

Fig. 8 – Crack distribution at failure.

4. Conclusions

When comparing the real life test and the 3D FEM model we draw the following conclusions:

a) in therms of failure force the difference was approx. 10% (acceptable);

b) in therms of displacements further calibration needs to be made (in development);

c) failure mechanisms are similar in both cases;

d) after calibration, this model will be used for further parametric studies on highway beams with similar sections.

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STUDIU COMPARATIV REALIZAT PE GRINZI DE AUTOSTRADĂ IN CEEA CE PRIVEŞTE FORŢA ŞI MODUL DE CEDARE ÎNTRE MODELUL EXPERIMENTAL ŞI MODELUL 3-D CU ELEMENTE FINITE

(Rezumat)

Se prezintă un studiu comparativ între experimentul realizat în 2008 asupra unei grinzi chesonate de autostradă, precomprimată şi prefabricată, cu o deschidere de 37.1 m., supusă la forţe concentrate în 4 puncte, încărcată până la cedare în 6 cicluri de încărcare-descărcare, şi modelul 3-D realizat cu elemente finite, încărcat, modelat ca şi o replică identică a experimentului. Motivul modelării 3-D cu elemente finite a fost realizat pentru a observa mai în detaliu distribuţia eforturilor, deformaţiilor şi distribuţia fisurilor în interiorul grinzii. De asemenea, realizarea unei calibrări corespunzătoare a modelului în vederea realizării unui studiu parametric în viitor, variind diverse aspecte cum ar fi: aplicarea încărcării, grosimea secţiunii, gradul de pretensionare, etc.

Rezultatele obținute pot oferi informații importante luând în considerare nesecitatea țării noastre de realizare rapidă a unei infrastructruri moderne. Validitatea modelului propus este demonstrată prin compararea rezultatelor cu cele obținute de INCERC. Acest experiment a fost cea mai importantă încercare distructivă realizată în România pe o grindă chesonată prefabricată şi precomprimată