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ON DYNAMICS OF LIFT BRIDGE

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Abstract. *The paper deals with probabilistic analysis in dynamics. The Botlek bridge (Rotterdam, Holland) – one of the largest vertical movable lift bridges in the world is analyzed. The structure of the bridge consists of six reinforced concrete pylons and two large (94 m x 49 m each) steel decks connected through ropes with counterweights. The bridge system is in dynamic mode during movement of the decks and the counterweights, under the action of wind and earthquakes, under traffic loads in operation position. The real bridge structure has a high level of importance and accordingly not only deterministic analyses were carried out but also stochastic analyses were required. The paper focuses the probabilistic analysis as the base of dynamic study in the design process of the bridge. The results had a high significance for practical application and for design of the bridge. The uncertainties of pylon and deck: stiffness and weight were taken into account in the probabilistic simulation method.*

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1 INTRODUCTION

The new Botlek bridge recently built in Rotterdam, Holland (see Figure1) is one of the largest vertical movable lift bridges in the world. The Vienna Consulting Engineers ZT GmbH [1] was responsible for the structural design. In frame of the design process of the bridge, the finite element model was created and analyzed using deterministic approach in statics and dynamics [2, 3] on the base of Eurocodes [4, 5]. The dynamic analysis was required due to wind loads, seismic loads, traffic loads and operation loads by movement of decks. The Botlek bridge has a high level of importance and accordingly not only deterministic analyses were carried out but also stochastic analyses were required. The paper focuses the probabilistic analysis as the base of dynamic study in design process of the bridge. The uncertainties of pylons and decks: stiffnesses and weights were taken into account in the probabilistic simulations.

Figure 1: Botlek bridge, Rotterdam – visualization.

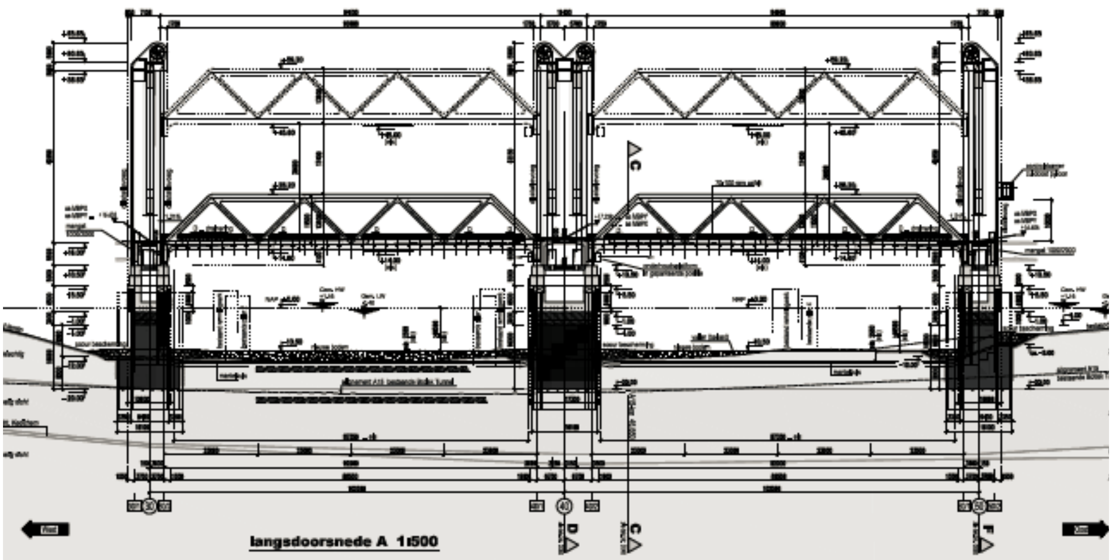


Figure 2a: Botlek bridge project: layout.

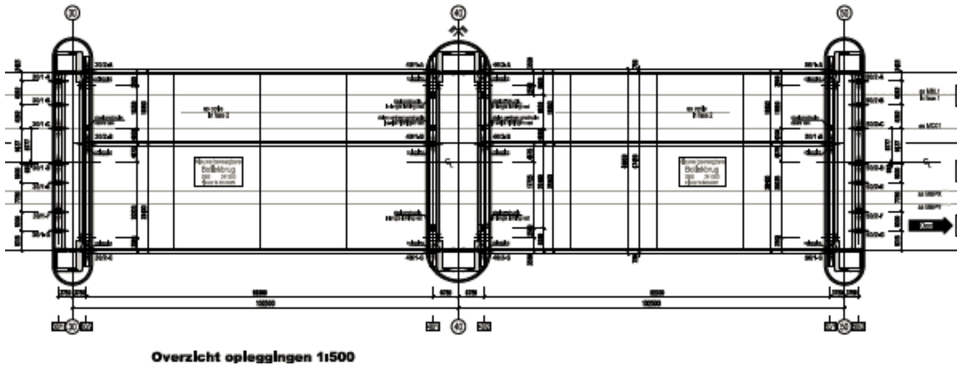


Figure 2b: Botlek bridge project: plan view

2 STRUCTURE

Two steel decks, more than 4000 tons weight each, are independently vertically movable on six concrete towers – the lifting height is 31 m. The length of steel decks is 94 m, the width 49 m (the size of each deck equals approximately playing field of soccer). The lifting system is fully balanced. The four concrete counterweights are guided on concrete pylon towers and are connected through ropes with decks at their ends.

3 FINITE ELEMENT MODEL

The finite element software ANSYS [2, 3] have been used for all models and analyses. The model of the bridge was prepared for deterministic and consistently for probabilistic analysis.

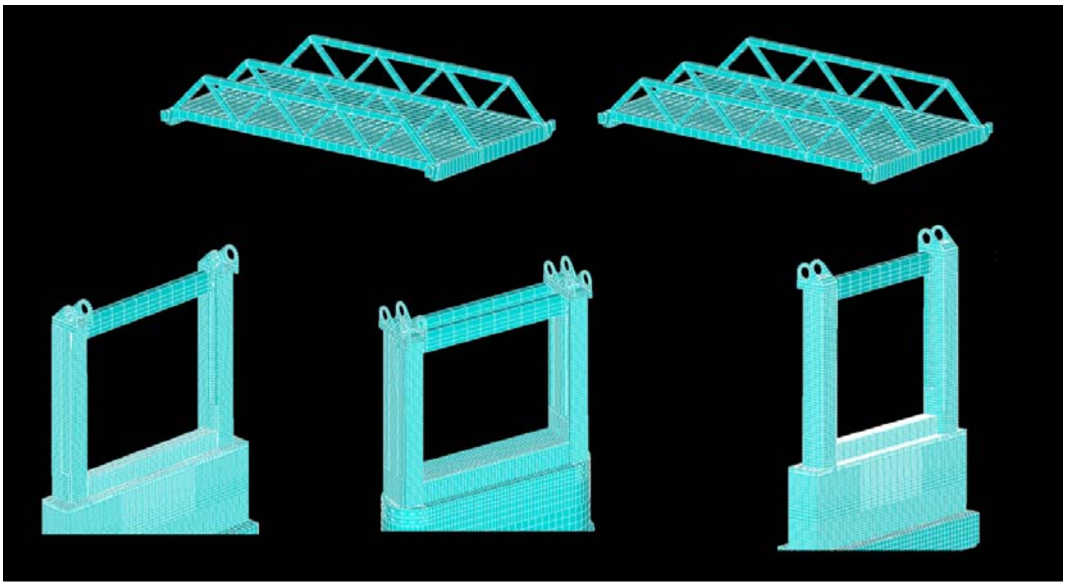


Figure 3: Bridge system: pylons with counterweights, decks.

3.1 Model of the structure

The preliminary analyses have shown, that the vertical displacements of the tops of the pylons are neglectable in comparison to the horizontal displacements [1]. For that reason was the simplification of the model in 2D possible. The model consists of two approximately rigid plates (decks) with weight G and substituted thickness H, models of pylons - springs with stiffnesses K1-K12 (see Figures 4 and 5).

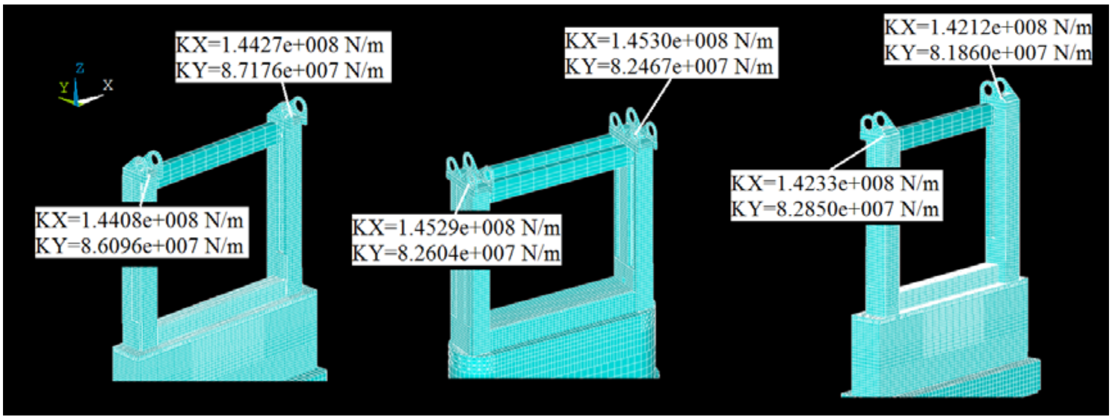


Figure 4: Horizontal stiffnesses of pylons: input in deterministic analysis.

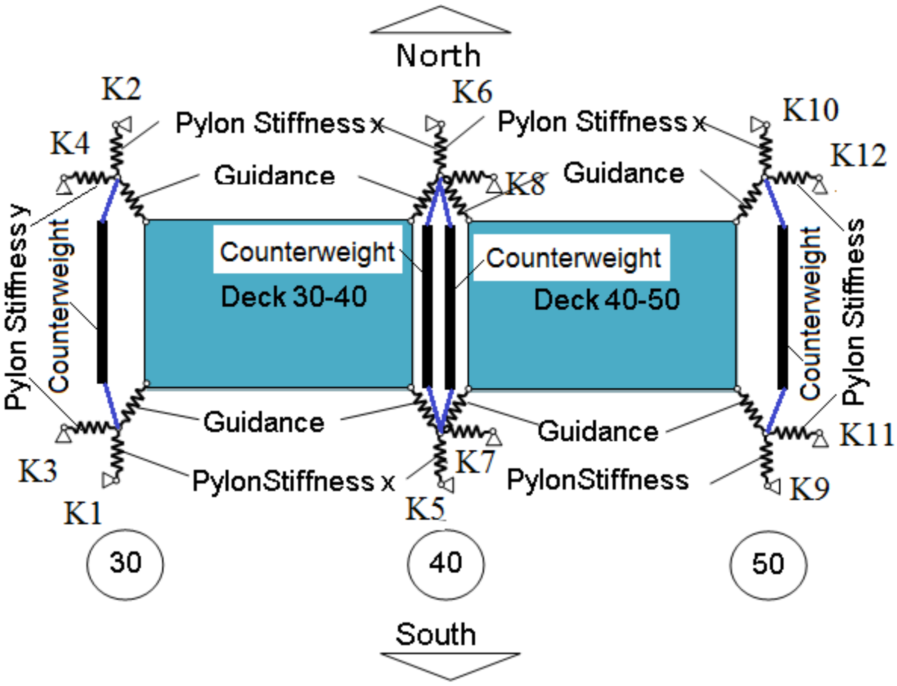


Figure 5: 2-D model.

4 DYNAMICS

4.1 Dynamic loading

Let consider from dynamics unfavorable situation when the both decks are in upper position. The mass more than 9000 tons is in the height of more than 30 m supported by six pylons. The system is sensitive to horizontal loading e.g. wind loading, seismic loading. The bridge structure can be analyzed according to Eurocode procedures [4, 5].

4.2 Modal analysis

The natural frequencies and modes of the bridge system influence the dynamic behavior of the bridge system. The dynamic component of the loading depends on the base of Eurocode [4, 5] and on natural frequency of the structure. The first three modes are presented in Figures 6-8. The eigenvalue problem was solved with Lanczos method.

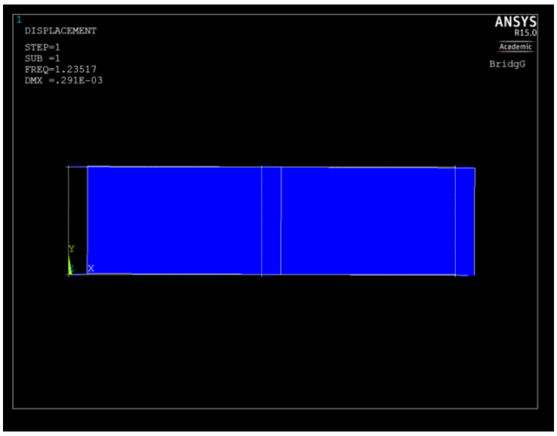


Figure 6: The first mode.

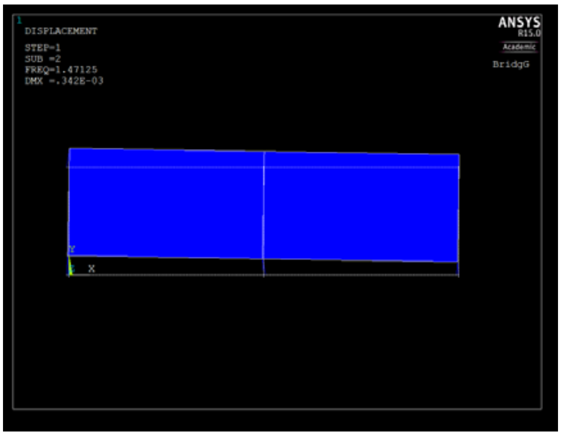


Figure 7: The second mode.

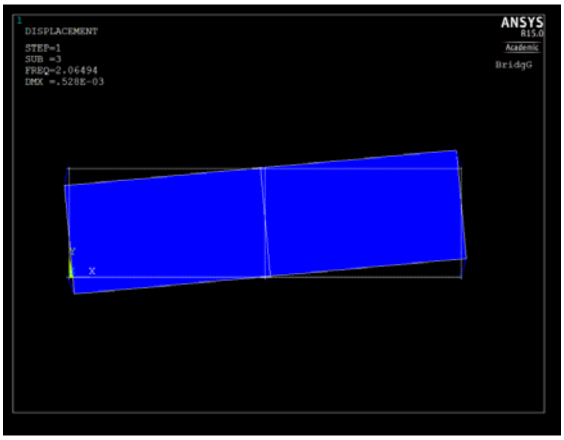


Figure 8: The third mode.

5 PROBABILISTIC ANALYSIS

The deterministic model introduced above is executed in ANSYS multiple times during probabilistic analysis. A special macro for probabilistic analysis was written in APDL language [2, 3]. Random input parameters: horizontal stiffnesses K1-K12 of pylons, weight G of deck and substituted thickness H of the deck are defined by Gaussian distribution. The mean values are resumed from preliminary deterministic analysis. The standard deviation of pylon stiffness is high because of the soil stiffness, which is included in it. The probability density functions and cumulative distribution functions of input are shown in Figure 9. The distribution parameters of all springs K1-K12 are the same.

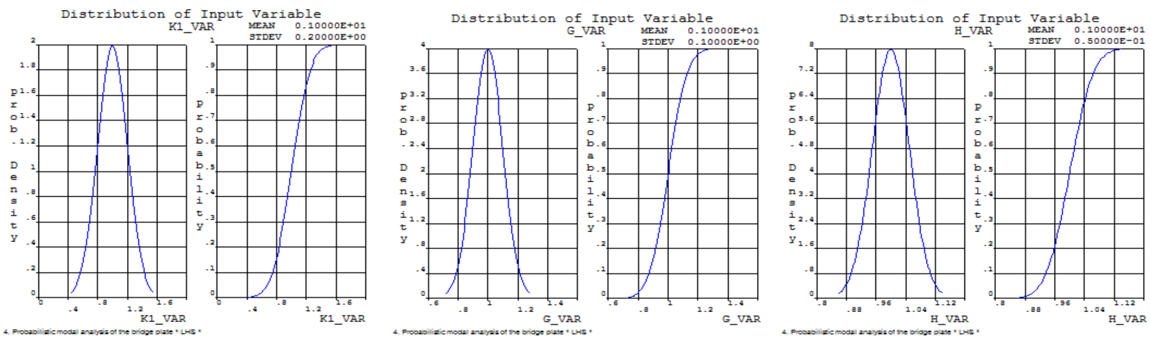


Figure 9: Probability densities and cumulative distributions: a) pylon stiffness K1-K12; b) deck weight, c) substitutional deck thickness.

The Latin Hypercube Sampling (LHS) technique for Monte Carlo Simulation was applied. Simulation with 300 samples was executed.

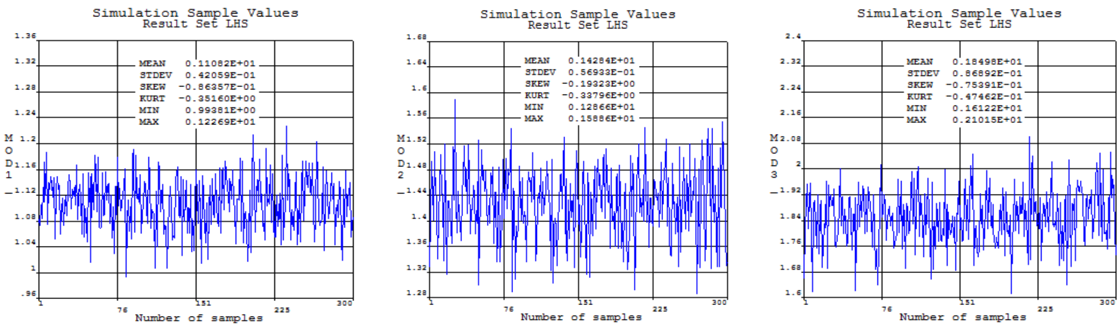


Figure 10: Simulation a) mode 1 b) mode 2 c) mode 3.

Cumulative distribution functions of input variables are presented in Figures 11-14.

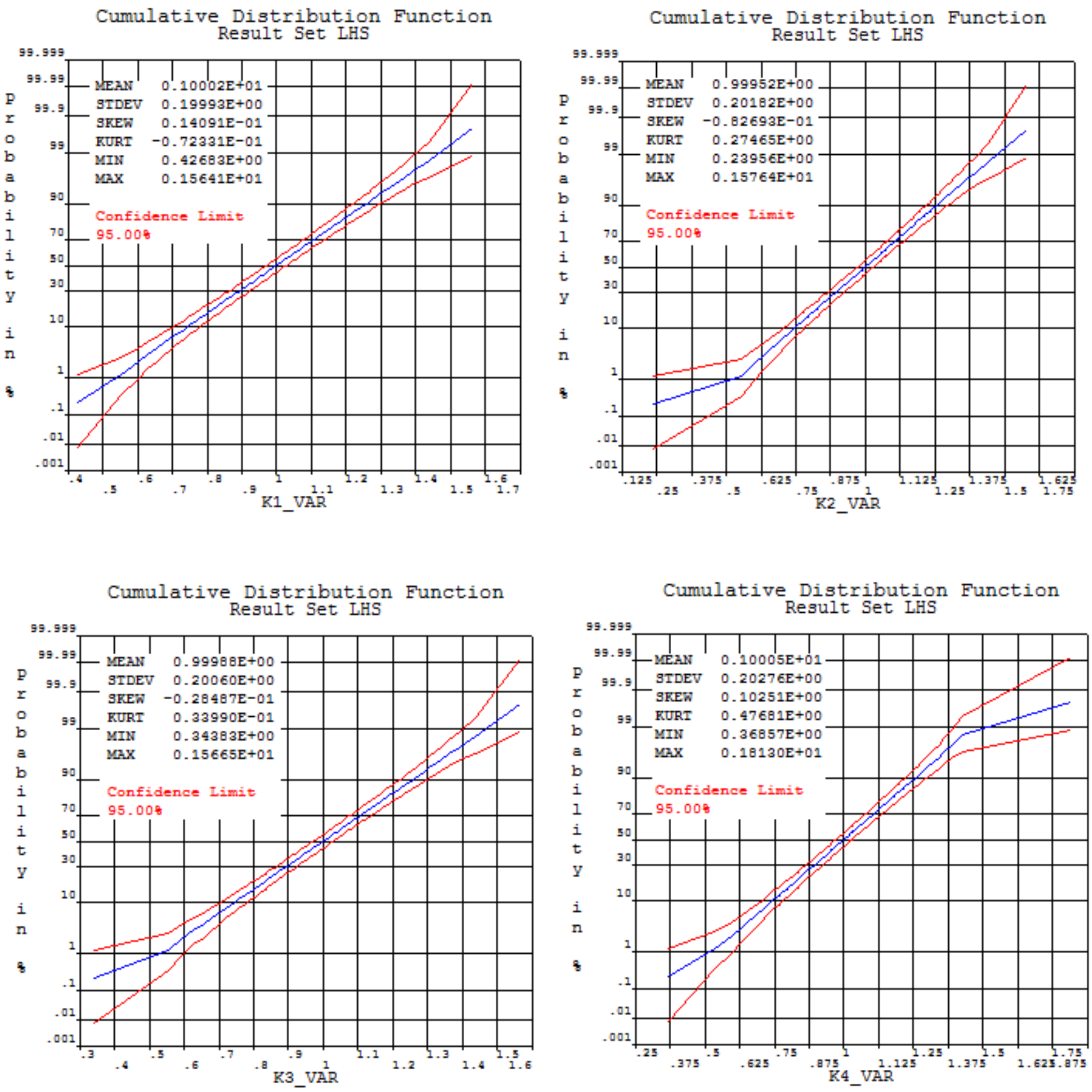


Figure 11: Cumulative distribution function of spring stiffnesses K1 - K4.

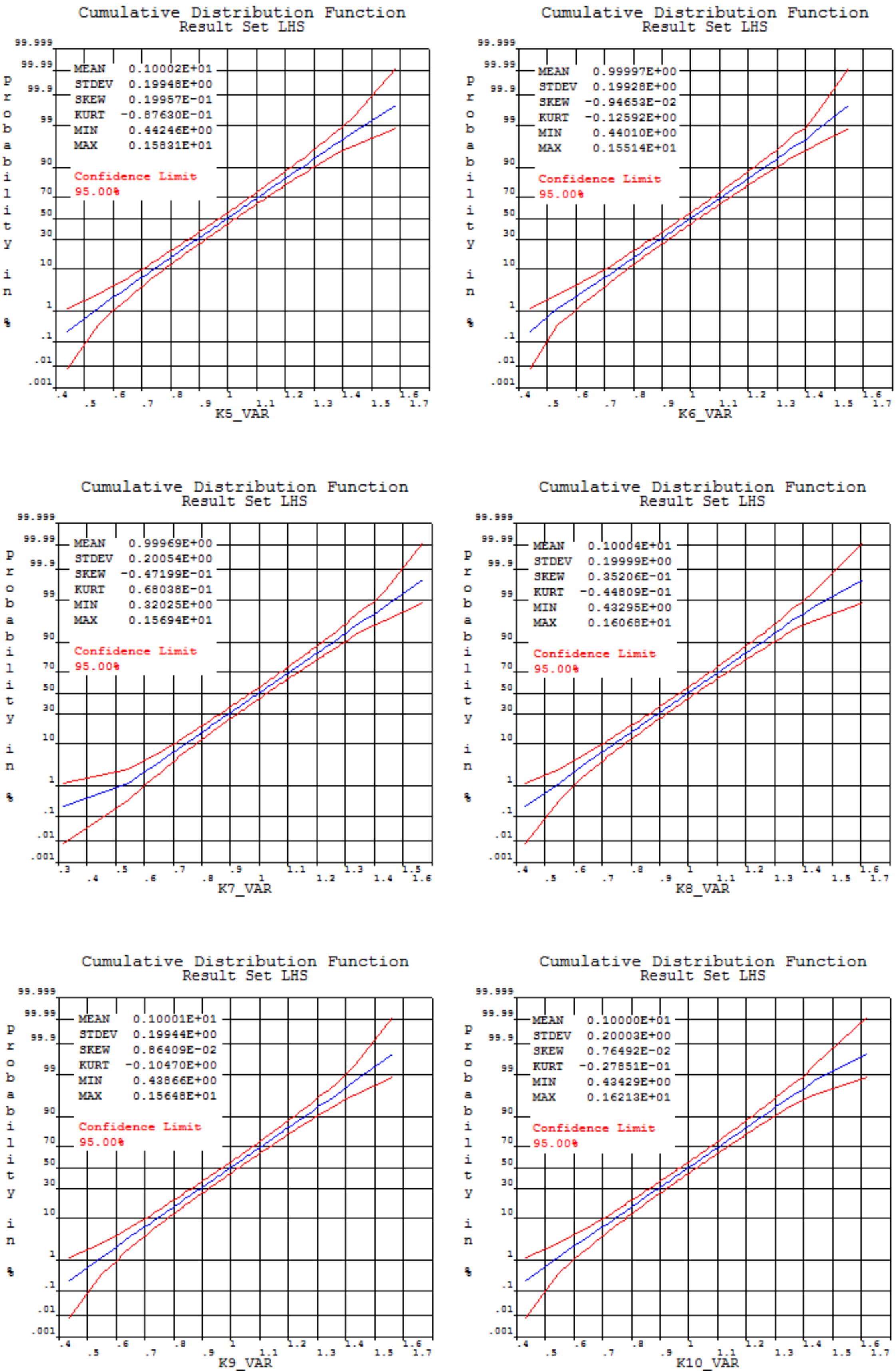


Figure 12: Cumulative distribution function of spring stiffness: K5-K10.

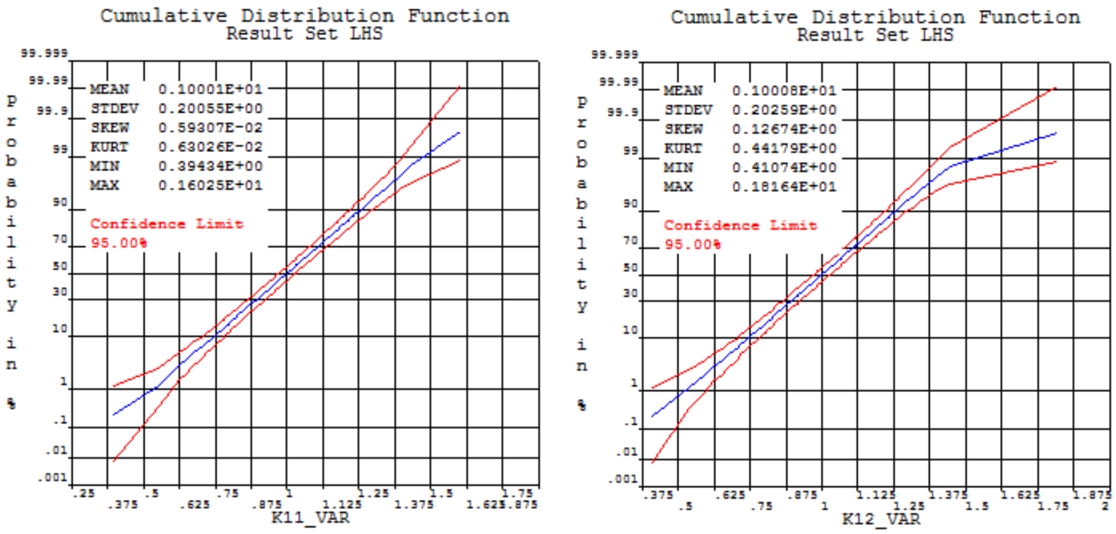


Figure 13: Cumulative distribution function of spring stiffness: K11-K12.

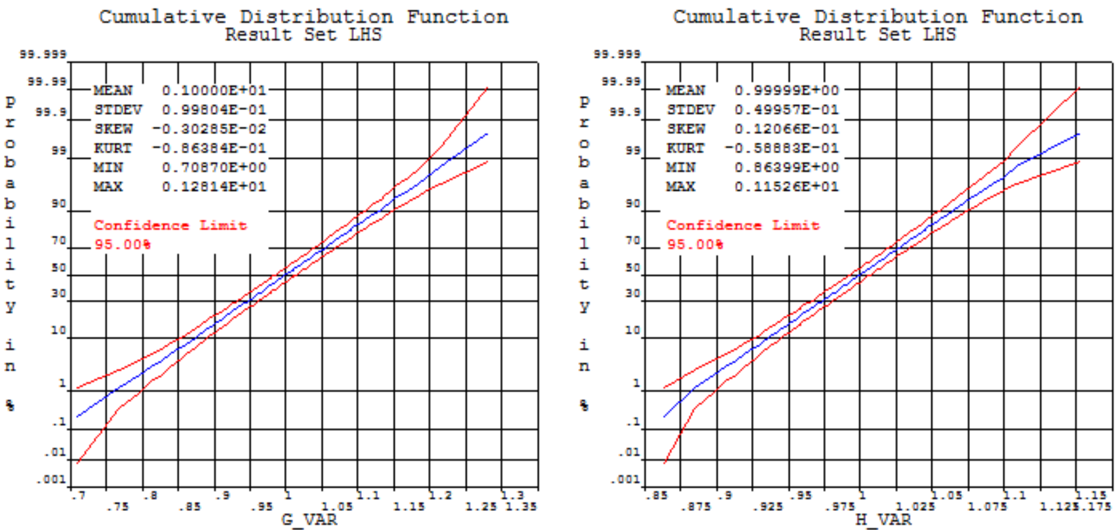
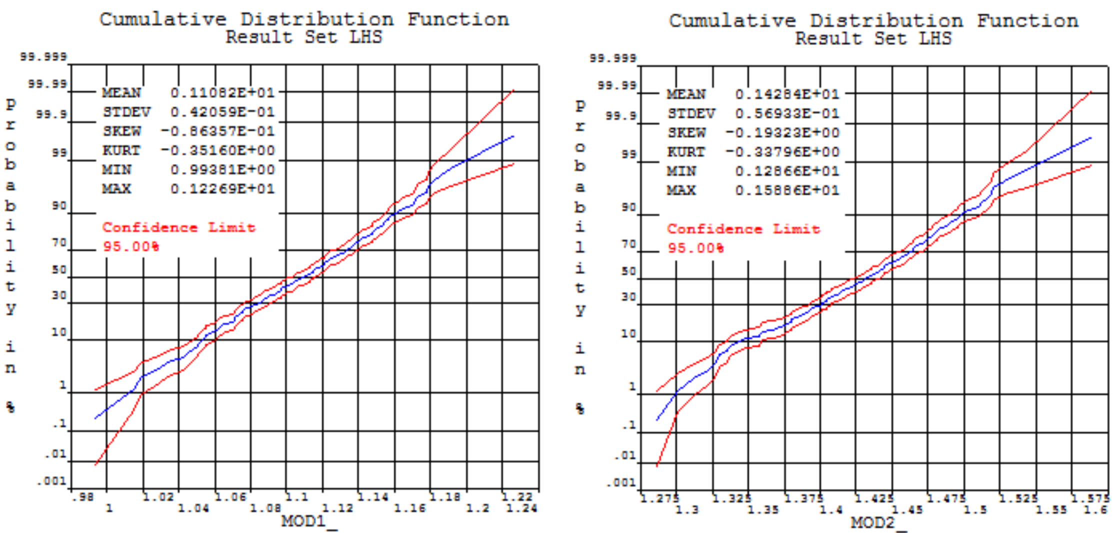


Figure 14: Cumulative distribution functions of weight and substitutional deck thickness.

The Cumulative distribution functions of output parameters are presented in Figure 15.



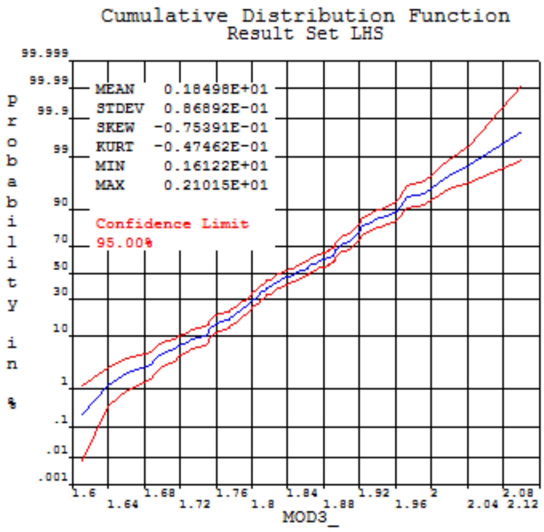


Figure 15: Cumulative distribution functions of modes 1-3.

The sensitivities of modes on stiffnesses and deck weight are presented in Figures 16-18.

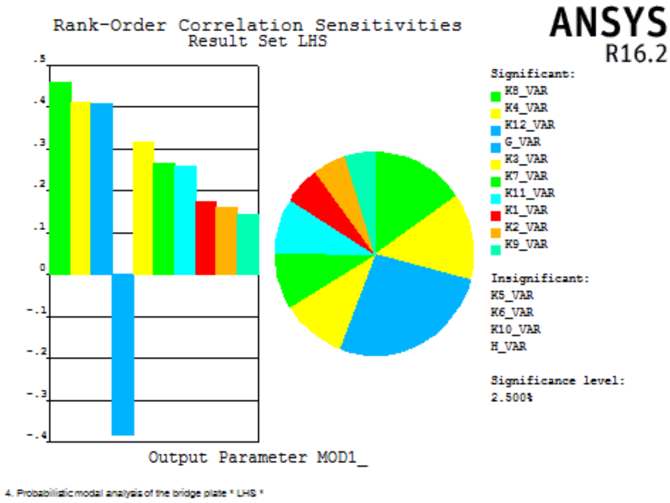


Figure 16: Sensitivities of 1st natural frequency on stiffnesses K1-K12, weight and substituted thickness.

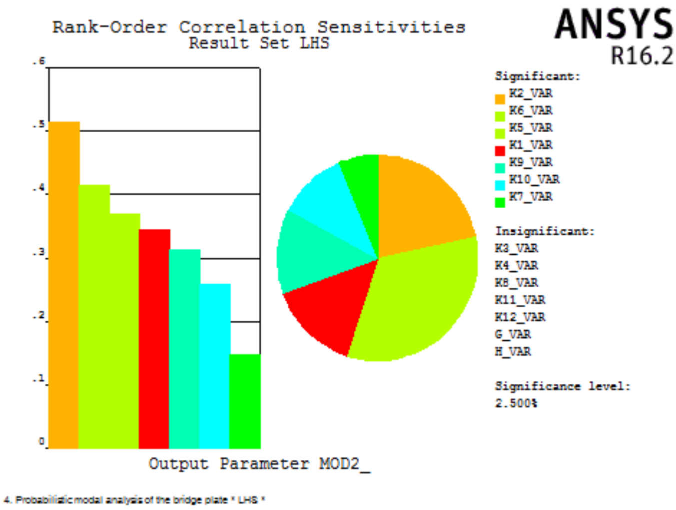


Figure 17: Sensitivities of 2nd natural frequency on stiffnesses K1-K12, weight and substituted thickness.

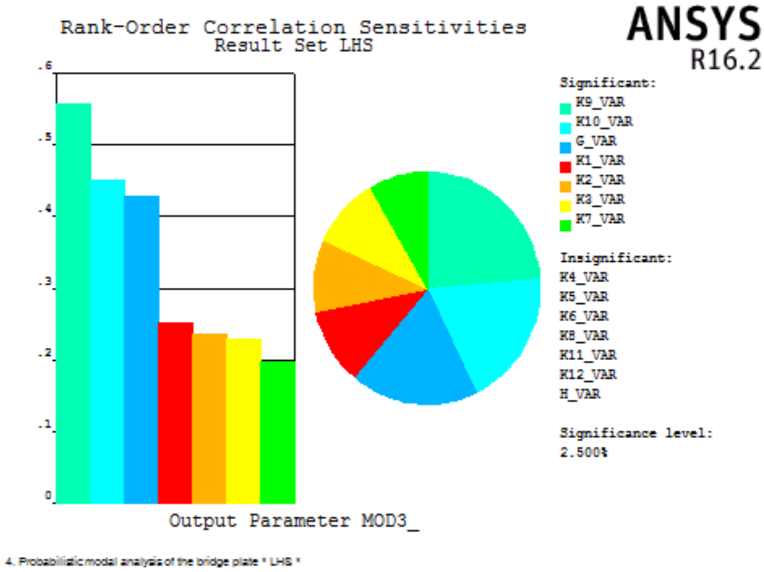


Figure 18: Sensitivities of 3rd natural frequency on stiffnesses K1-K12, weight and substituted thickness.

The resulting sensitivities (Figures 16-18) correspond to the modes in Figures 6-8 and to the correlation coefficients between input and output (see Table 1). The

Out\Inp	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	G	H
MOD1	0.182	0.181	0.345	0.421	0.070	0.028	0.271	0.434	0.174	0.087	0.244	0.392	-0.389	-0.084
MOD2	0.353	0.546	0.079	-0.016	0.347	0.431	0.169	-0.029	0.326	0.270	0.005	-0.080	-0.043	0.002
MOD3	0.238	0.231	0.253	-0.050	-0.102	0.112	0.206	-0.065	0.590	0.478	0.064	-0.023	0.440	0.074

Table 1: Correlation coefficients Output/Input.

6 SUMMARY

The contribution presents the probability analysis results of the movable bridge. The decks were considered in top position. The stiffness of the pylons inclusive soil and weight of decks were defined as random input variables. First, second and third natural frequencies were defined as output parameters. The impact on modes is presented. The results are useful in dynamic analysis on the base of Eurocode.

7 CONCLUSIONS

- The influence of stochastic input variables: stiffness of pylons inclusive soil and weight of decks on natural frequencies and modes are presented.
- The resulting natural frequency range is shown in dependence on pylon+soil stiffnesses and mass (input defined by Gaussian distribution).
- The decisive springs for particular modes are shown:(see Table 1 and Figures 16-18):

  Mode 1: horizontal springs in Figure 5: K8, K4, K12, K3, K7, K11

  Mode 2: vertical springs in Figure 5: K2, K6, K5, K1, K9, K10

  Mode 3: vertical springs in Figure5: K9, K10, K1, K2

- The sensitivities of modes on particular pylon stiffnesses are presented.
- The obtained results are useful for seismic and wind loading calculation.
- The results provide the overview about dynamic behavior of the bridge.

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