NUMERICAL SEISMIC ANALYSIS OF THE MAIN GIRDER OF A DOUBLE-GIRDER BRIDGE CRANE

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In this paper a numerical analysis of a double-girder bridge crane was carried out in order to evaluate the seismic response of the main girder. The analysis includes static, modal and transient FEM analyses in Ansys, with the aim of obtaining a realistic picture of the structural behavior under earthquake excitation. Through the static analysis, the reference values for stresses and deformations under working conditions were obtained, while the modal analysis identified the natural frequencies and the dominant vibration modes. The transient analysis, performed with the real earthquake record El Centro, provides the time histories of displacements, accelerations and stresses at characteristic points along the span. The results showed that the seismic excitation causes increased and time-variable responses compared to the static values, but the structure remained in the elastic domain. The applied approach enables a more detailed representation of the dynamic effects on the girder and serves as a basis for more detailed inspection control of bridge cranes.

Keywords: bridge crane, main girder, modal analysis, transient analysis, Ansys

1. INTRODUCTION

In industry, cranes are used for most processes, and in the largest percentage bridge cranes are applied. The condition of bridge cranes is essential both for safe operation and for the overall efficiency of the production process. In order to perform inspection, maintenance and proper use of cranes, it is necessary to apply a series of standards, regulations and laws [1, 2]. In our country, there is a Regulation for the use of cranes and industrial transporters, as well as a Law on technical inspection [3], [4], [5]. The regulation and the law define guidelines for inspection procedures, inspection intervals and the

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required documentation. However, in the current national regulation for cranes in the Republic of North Macedonia there is no explicit requirement for performing detailed seismic analysis of bridge cranes, as is the case for building structures according to Euro code 8. Although seismologically North Macedonia belongs to a zone of moderate to high seismic activity, as part of the South-European–Mediterranean seismic belt, seismic requirements for bridge cranes remain insufficiently addressed in national technical regulations. Bridge cranes, which are almost an inseparable part of every industrial facility, contain moving elements, contact surfaces and masses that are not rigidly connected to the main structure [9], [10], [11]. This makes them more sensitive to earthquake excitation and requires detailed analysis to ensure safe operation under extreme conditions [12-14].

The need for such research is supported by a review of previous studies in the fields of crane engineering reliability, assessment, maintenance, regulations and standards for crane use, as well as seismology research on the Balkans.

From the literature review [1], [2], [6], [7], [8] it is evident that bridge cranes are widely used, and the main girder represents their most loaded element, directly affecting the load-carrying capacity and safety of the crane. The national regulation [1], [2] covers technical inspection procedures, but at no point requires mandatory seismic analysis of bridge cranes. On the other hand, studies [9], [10], [11], [12] point out that the Balkans represent one of the most active seismic regions in Europe, with a total of 15,417 earthquakes recorded on the territory of North Macedonia in the period 2010–2021 [9]. Previous research indicates that bridge cranes may exhibit significant nonlinear behavior during earthquakes, as a result of their structural configuration [13-18].

Study [13] presents a methodology for simulating bridge cranes under seismic loading based on the SOCRAT benchmark. The models are calibrated with experimental results and later used for blind nonlinear predictions under high seismic intensities. The approach uses shell elements for the crane structure, connector elements for rail interaction with frictional behavior, and an explicit dynamic procedure for severe earthquakes. Research [14] focuses on the static and dynamic stability of tower cranes, emphasizing their sensitivity to destabilizing effects such as wind and seismic actions. Stability is identified as a key parameter in crane design, especially for tall and flexible systems. In [15], a numerical reliability assessment of pre-stressed concrete bridges is performed through time-domain analysis with material nonlinearity. The study shows that damping and earthquake parameters (PGA, magnitude) significantly influence reliability, while geometric variations have a smaller effect. Study [16] investigates the vertical seismic response of equipment with low vertical stiffness, using a 150-ton overhead crane as an example. Scale-model tests and nonlinear time-history analyses show strong amplification of the vertical response, with numerical results closely matching experiments. Research [17] analyzes the influence of overhead cranes with a hanging load on precast industrial buildings during the 2012 Emilia earthquake sequence. Simplified and 3D nonlinear analyses reveal that parameters such as damping, rope length and structural ductility affect roof displacements and horizontal forces transmitted by the crane. Study [18] examines the nonlinear seismic behavior of a steel warehouse equipped with an overhead crane. Using pushover and time-history analyses with Chilean earthquake records, the authors conclude that crane loads do not significantly affect the global seismic performance of the warehouse, although directional ductility varies. More recent work emphasizes FEM-based structural optimization. Study [19] applies analytical calculations and finite element analysis to optimize girder cross-sections, reducing unit weight without compromising structural capacity. In [20, numerical analysis of an EOT crane girder is carried out to evaluate deflections under rated loads. Results confirm that girder deformations remain within allowable limits, validating the structural design. Research [21] models a bridge crane structure in ABAQUS and analyzes stresses and displacements under typical operating conditions. Comparison between theoretical and FEM results highlights the higher accuracy and practical value of FEM for crane design. Finally, study [22] compares analytical and numerical results for a single-girder crane using Catia and Ansys. The FEM analysis produces slightly lower but consistent results relative to analytical calculations, demonstrating the reliability of numerical simulations for main girder evaluation.

Overall, the literature review showed that although the country belongs to a seismically active region, there are very few studies related to seismic analyses of bridge cranes, especially in the Balkans, which is the second most

seismically active region in the world after the Pacific "Ring of Fire."

2. METODOLOGY

The methodological approach in this paper is based on integrating static, modal, and transient numerical analyses to evaluate the seismic response of the crane's main girder. The static results from Ansys Workbench and the dynamic results from Ansys Mechanical APDL are used jointly to identify critical regions and assess structural behavior under earthquake loading [23], [24]. A real ground-motion record (El Centro) [25] is applied in the transient analysis, while the modal results support the understanding of the girder's dynamic sensitivity. The phases of the research are presented in Figure 1.

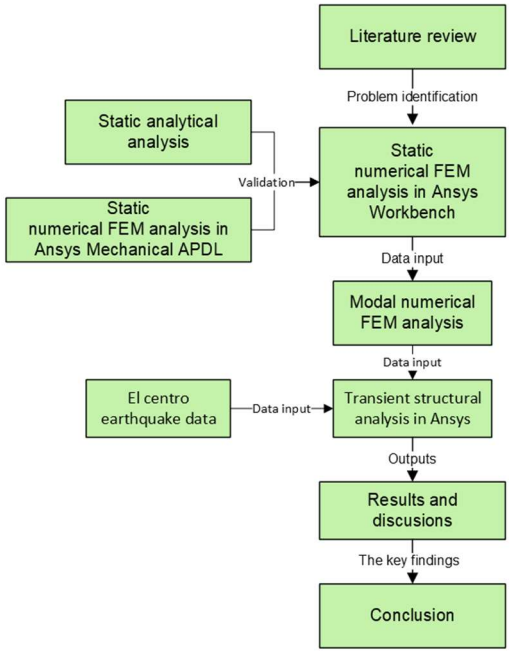


Figure 1. Methodology flowchart

3. NUMERICAL ANALYSIS

In this study, static, modal and transient dynamic analyses were performed in Ansys on the main girder located at the Institute of Earthquake Engineering & Engineering Seismology – IZIIS. The main girder of the bridge crane is a welded box profile, and its geometry and material properties were taken from the crane documentation (Table 1) [6]. Before the static analysis, a numerical analytical calculation was carried out, from which it was obtained that the maximum moment occurs at approximately 12.8 m from the left support and is about $M_{max} \approx 150$ kNm, while the bending stress is $\sigma_{max} \approx 99$ MPa. The analytical results serve as a basis for verification with the numerical analysis.

Table 1. Geometrical characteristics and exploitation parameters of the main girder

Characteristics / Parameters	Symbol	Value
Height of the girder	H	700 mm
Width of the girder	B	450 mm
Thickness of top/bottom plate	T	8 mm
Thickness of side plates	S1, S2	6 mm
Lifting capacity	Q	10 t
Span	L	16.24 m
Lifting height	H	9 m
Material	S235JR	
Elastic modulus	E	2.10×10^{11} Pa
Poisson's ratio	v	0.30
Density	ρ	7850 kg/m³
Yield strength	fy	235 MPa
Stressallow	σ_{allow}	≈ 0.6·fy = 141 MPa

3.1. STATIC ANALYSIS

The CAD model created in SolidWorks was transferred into ANSYS Workbench [24], [25]. The CAD model of the main girder is shown in Figure 2.



Figure 2. CAD model of the double-girder main girder

In the numerical simulation, the girder is treated as a simply supported beam, with one end vertically fixed and the other axially movable (Figure 3). The mesh is denser in the zones where stress concentrations are expected, around the supports and the trolley path, and coarser in the remaining parts. A mesh density check was performed, where further refinement did not produce stress variations greater than σ < 3%. This confirmed that the selected mesh was appropriate. Additionally, before performing the dynamic simulations, a static analysis was also carried out in Ansys Mechanical APDL for verification. The main girder was represented with a beam element (sectype, 1, beam, hrec), unlike the detailed 3D SolidWorks model in Ansys Workbench. The results showed an expected difference of around 10%, which is typical when comparing a simplified beam model created in Ansys Mechanical APDL with a full 3D model created in SolidWorks. The difference occurs because the beam model in APDL represents an idealized line geometry and therefore does not capture the local stress concentrations that are visible in the detailed 3D solid model in Workbench.

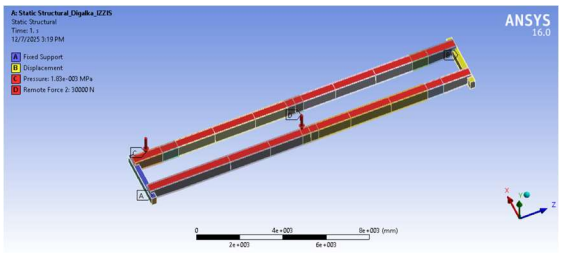


Figure 3. Static FE model with boundary conditions and mid-span load

3.2. MODAL ANALYSIS

The modal analysis was performed in ANSYS Mechanical APDL to determine the natural frequencies and mode shapes required for the dynamic evaluation. The same structural model and boundary conditions from the static analysis were used. The eigenvalue extraction was carried out with the LANB solver, requesting the first ten modes. Mode shapes were visualized using the SET and PLDISP commands, ensuring proper identification of the dominant vibration patterns needed for the subsequent transient analysis.

3.3. TRANSIENT ANALYSIS

The transient analysis was performed in ANSYS Mechanical APDL by applying the El Centro ground-motion record [25], scaled to 0.25 g and with a total duration of 10 s (Figure 4).

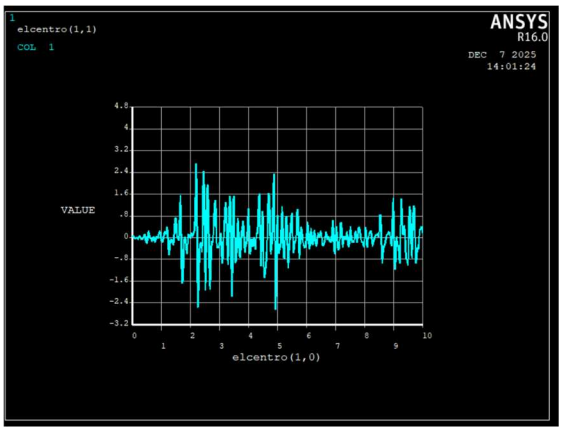


Figure 4. Input ground acceleration record (El Centro, 0.25 g)

Rayleigh damping was introduced with coefficients α = 1.277323 and β = 0.00178225, and the equations of motion were solved with a full direct integration scheme, using a constant time step of Δt = 0.02 s. The ground acceleration was applied as a vertical base excitation following an initial gravity step, while the vertical and horizontal displacements, accelerations, and equivalent (von Mises) stresses were monitored at three characteristic nodes along the main girder (left support, mid-span, and right support). The locations of the selected monitoring nodes are shown in Figure 5. The obtained time-history results were subsequently compared with the static response in order to assess the influence of seismic loading on the overall structural behavior.

Table 2. Basic transient-analysis parameters

Parameter	Value
Earthquake record	El Centro (0.25 g)
Total duration	10 s
Time step Δt	0.02 s
Damping (Rayleigh)	α = 1.277323, β = 0.00178225
Beam element	BEAM188
Mesh size	0.20 m
Output nodes	Left support, mid-span, right support

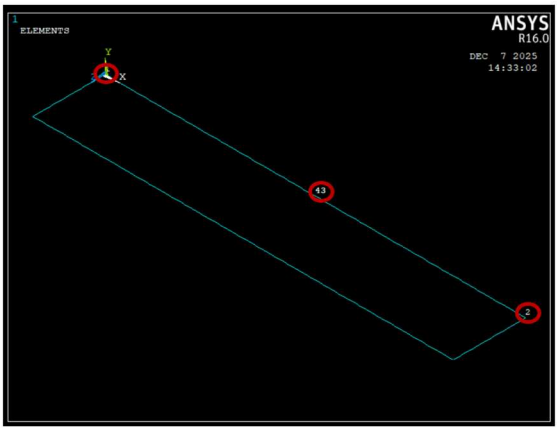


Figure 5. Selected monitoring nodes along the main girder used in the transient analysis

4. RESULTS AND DISCUSSION

4.1. STATIC ANALYSIS RESULTS AND DISCUSSION

In this study, only the simulations with the load positioned at mid-span are included, because the analytical calculation showed that the maximum stress occurs at that location. When the trolley is located at mid-span, the maximum stress is 155.59 MPa, while the deformation is 4.42 mm (Figure 6). From the figures (Figure 7), it can be seen that these are local stresses occurring at certain points of the girder, while the remaining part of the girder is subjected to stresses below the allowable limit (141 MPa).

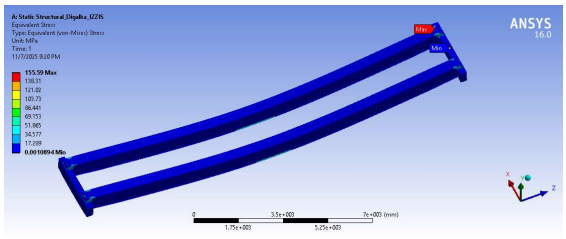


Figure 6. Equivalent von Mises stress distribution under static loading at mid-span

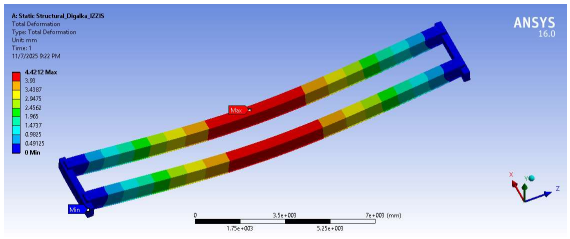


Figure 7. Total deformation of the main girder under static loading at mid-span

4.2. MODAL ANALYSIS RESULTS AND DISCUSSION

The first several modes exhibited near-zero frequencies, corresponding to rigid-body motions, while the first significant bending mode occurred at 0.66 Hz, followed by higher-order modes at 3.76 Hz and 4.05 Hz. These values indicate a flexible structural response, typical for long-span girders, and provide the basis for the subsequent transient seismic analysis. The extracted modal frequencies are summarized in Table 3. In Ansys, the deformed shape of the structure was obtained at a frequency of 3.76 Hz, which represents the dominant bending mode (Figure 8). This modal shape was essential for understanding the dynamic sensitivity of the girder and served as the basis for an accurate transient seismic analysis. The second vibration mode, obtained at a frequency of 4.05 Hz, exhibits a higher-order bending deformation along the girder span (Figure 9). Compared to the first mode, this mode involves more complex curvature and provides insight into the dynamic flexibility of the structure. These modal characteristics are essential for understanding the girder's response under seismic excitation.

Table 3. Natural frequencies of the crane girder

Mode	Frequency [Hz]	Mode direction
1	0.66	Vertical bending
2	3.76	Vertical bending
3	4.05	Vertical bending

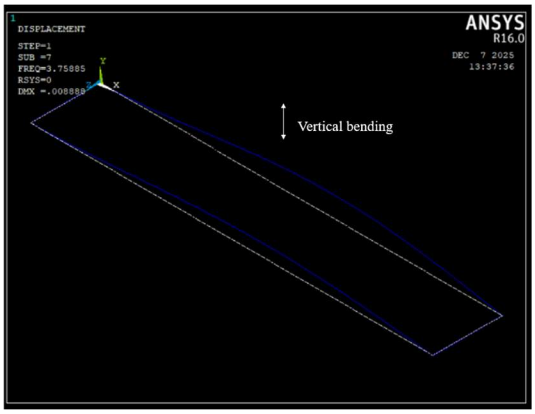


Figure 8. First vibration mode of the crane girder (f = 3.76 Hz)

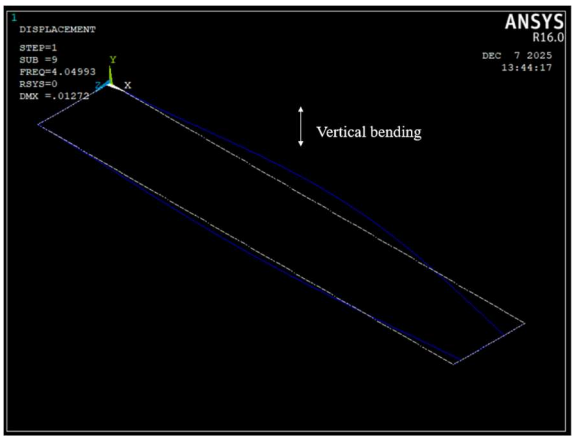


Figure 9. Second vibration mode of the crane girder (f = 4.05 Hz)

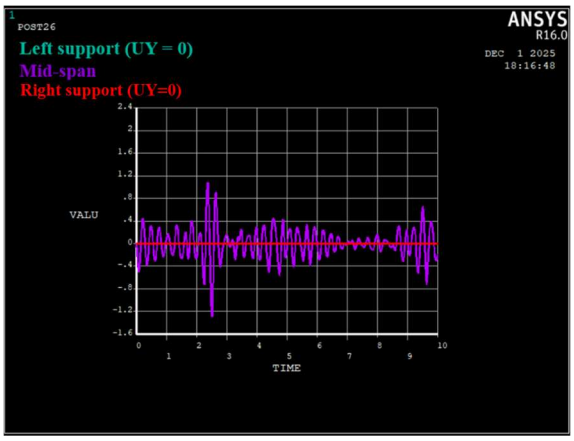


Figure 10. Time history of the vertical displacement UY at the three monitoring nodes (left support and right support UY=0)

4.3. TRANSIENT ANALYSIS AND DISCUSSION

The transient analysis performed using the El Centro earthquake record (0.25 g) showed that the dynamic response of the main girder is significantly more intense and time-dependent compared to the static cases. The largest vertical displacements and accelerations occur at the mid-span node (node 43), which is consistent with the expected behavior of a simply supported beam subjected to oscillatory excitation.

The time history of the vertical displacement UY at the mid-span shows several pronounced peaks during the strongest pulses of the earthquake, with a maximum negative deformation of approximately –12.88 mm and a maximum positive value of about +10.79 mm (Figure 10). Due to the fixed boundary conditions, no displacements were recorded at the support nodes; therefore, only the mid-span response is visible.

These values are larger than the static displacement but remain within the elastic range of the material. The vertical accelerations reach up to ±9.8 m/s², which is approximately equal to the gravitational acceleration (≈1 g) and indicates significant dynamic excitation.

Therefore, it can be concluded that the structure maintains its load-carrying capacity under the considered seismic excitation. Table 4 presents the extreme values of vertical displacements and accelerations obtained from the transient analysis at the three monitoring nodes.

Table 4. Peak transient response values at monitoring nodes

Node location	Quantity	Min value [mm]	Max value [mm]
Left support	ACCY [m/s²]	0.00	0.00
Mid-span	ACCY [m/s²]	–9.81	8.86
Right support	ACCY [m/s²]	0.00	0.00
Left support	UY [mm]	0.00	0.00
Mid-span	UY [mm]	–12.88	10.79
Right support	UY [mm]	0.00	0.00

Figure 11 shows the contour distribution of the equivalent (von Mises) stresses at the moment of maximum response. It is noticeable that the highest stresses occur near the supports and in the regions where the stiffness of the structure changes, which is typical for bending-loaded girders under dynamic excitation. Although pronounced local peaks are present, the maximum value on the order of $1.13 \cdot 10^8$ Pa (113 MPa) remains below the yield strength of S235JR steel, indicating that the structure stays within the elastic domain even under seismic conditions.

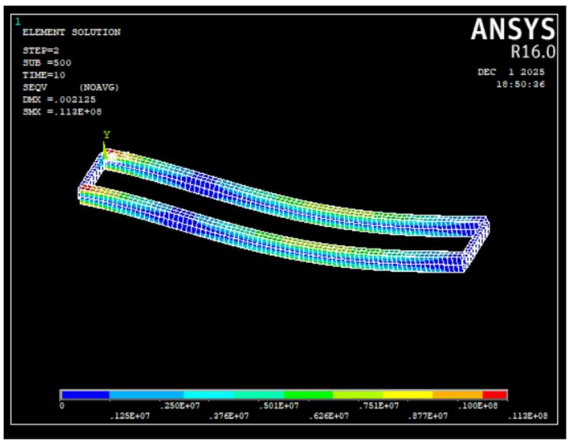


Figure 11. Contour distribution of equivalent (von Mises) stresses at peak seismic response

Based on the obtained results, it can be concluded that the seismic excitation produces a combined bending and inertial response, with momentary peaks that exceed the static behavior. However, the structure remains within the elastic domain and does not show signs of damage under the considered earthquake intensity.

5. CONCLUSION

This study presented a numerical approach for assessing the seismic response of the main girder in a double-girder bridge crane, using static, modal and transient analyses under real earthquake excitation. The static analysis showed that the girder operates within the elastic domain under nominal service loading. The modal analysis identified the dominant natural vibration modes and indicated that the low natural frequencies are characteristic of long and flexible structures, suggesting that dynamic effects can have a significant influence on their behavior during an earthquake.

The transient analysis based on the El Centro earthquake record showed that the largest structural responses occur at mid-span. The maximum vertical displacements reached approximately 10–13 mm, while the equivalent (von Mises) stresses remained below 113 MPa. These results indicate that the structure retains its load-carrying capacity and does not enter the plastic range under the considered seismic intensity.

Overall, the results confirmed that earthquake excitation causes increased deformations compared to static conditions, but the structure remains safe. The analysis shows that static calculations alone are not sufficient for fully understanding the behavior of bridge cranes under seismic loading, and that transient dynamic analyses represent a necessary step for realistic evaluation of their safety and performance. The applied methodology can serve as a basis for future assessments, inspections, and the development of monitoring systems for bridge cranes in seismically active regions.

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