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COMPARISON OF TRUSS BRIDGE STRUCTURES DESIGNED FOR CONVEYOR BELT SYSTEMS

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Abstract: In open-pit mines, the installation of conveyor belt tracks may require conveyor bridges to span the terrain or existing structures. The paper compares the structural design options for truss bridge structures, with a particular focus on existing, recycled structures and prefabricated, modular elements. Three-dimensional finite element simulations were used to verify the first option, which is an existing structure meant for reuse to look at the natural frequencies, stress distributions, and deformed shapes. These results highlight the importance of investigating the vibrations caused by the movement of the conveyor belt and the wear of the rollers. The other option examined is a commercial solution based on a Bailey bridge, which is a portable, prefabricated, modular truss bridge designed for quick assembly without heavy equipment. The advantage of the modular design is that the structure can be reinforced by combining the elements, thereby increasing operational safety and economy.

Keywords: *bridge for conveyor system, truss structure, FEA, modal analysis*

1. INTRODUCTION

In open-pit mining operations, the installation of a conveyor bridge may serve multiple purposes. Various materials can be efficiently transported using conveyor belts in mining operations, but site-specific terrain conditions, such as crossing working pits or other conveyor systems, often pose challenges during installation. The study focuses on comparing structural design options for the conveyor bridge truss used to support long-distance conveyor belts. The interconnected triangular arrangements in the truss make the structure strong and lightweight.

The bridging solution can be achieved either by reusing an existing truss structure, originally designed for different material transport purposes and requiring modification, or by employing rapidly deployable, prefabricated modular bridge frameworks. Truss bridges are primarily evaluated through strength calculations and buckling checks of compressed members. An additional consideration is the analysis of vibration effects, which are consistently problematic in conveyor belt routing. For rapidly deployable modular bridges made of mobile components, decision-making involves not only mechanical considerations but also economic factors alongside existing product specifications.

Ladányi (2018) presented results for an existing structure intended for reuse, where the spatial framework was simplified as a planar truss for strength verification. The required parameters were determined primarily through manual calculations based on theoretical considerations. These calculations can be refined by reducing the load distribution obtained from finite element analysis (FEA) to a planar model of the bridge. Szirbik et al. (2023) further investigated the structure by making a 3D model, providing an opportunity to also study vibrational behavior (Szirbik et al., 2024).

The eigenvalue extraction used to calculate eigenfrequencies and mode shapes is based on the Lanczos iteration method (Bathe, 1996). The modal analysis starts with higher numerical accuracy eigenvalue calculations, followed by the generation of mode shapes. The natural frequencies and associated mode shapes can be used later to analyze the effects of dynamic loads on the structure, such as forced vibration analysis. The bridge structures under study support a conveyor system connected to framework elements, which are subjected to transient vibrations induced by the belt's motion. These vibrations may arise from the wear or failure of conveyor belt rollers, acting as excitation sources. Knowledge of the structure's natural frequencies is critical for managing the vibrations under any external effect. The slender member forming the bridge framework inherently causes low natural frequencies, making such structures easily excitable and requiring regular monitoring. In frameworks exposed to excitations due to conveyor-belt motion, resonance catastrophe may occur if the excitation frequency matches any structure's natural frequency. Such resonance can lead to failure, typically manifested as fractures in the weakest components, disrupting the mechanical transport system functionality. Due to the potential hazards of resonance catastrophes, vibration analyses are conducted on various mining equipment, such as excavators and disc-cutting rock extraction machines, as reported by Popescu et al. (2020) and Wijaya et al. (2022).

The costs of modifying an existing framework must be compared with the price, load-bearing capacity, installation costs, and dimensions of an alternative mobile bridge, as well as certain comparable mechanical properties.

2. STRUCTURAL DESIGNS

An alternative to design is an existing conveyor bridge that has been repeatedly utilized in open-pit mining operations to facilitate the installation of conveyor belts for transporting overburden and lignite. The other alternative is a solution constructed from mobile, prefabricated elements with specified manufacturer dimensions. The purpose of the structure is to avoid level intersections of conveyor belts and to bridge working pits during mining operations at low cost.

The truss structure of the first solution has undergone multiple modifications and reinforcements, resulting in its current examined configuration, which features an asymmetric design due to these developments. The structure, with principal dimensions of 23 m in length, 3 m in width, and 2.3 m in height, consists of ten equal-length segments. The diagonal cross-braces are oriented perpendicular to each other; however, unlike conventional designs, the arrangement is asymmetric, as illustrated in Figure 1. Specifically, the orientation of the cross-braces is identical in six cells but opposite in the other four. Wind bracing trusses are present at both the top and bottom of the structure. The conveyor bridge is reinforced at both ends by robust portal frames, and the entire structure is constructed using welded connections.

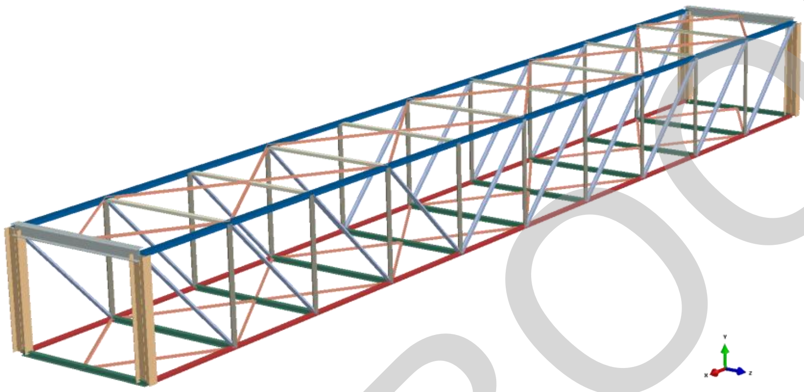

Figure 1
Geometry of the welded truss bridge structure in 3D

During the design of the welded truss framework, the lower cross-braces are constructed from W-section steel profiles with a height of h = 100 mm, while the upper cross-braces utilize T-section profiles with a height of h = 75 mm. The lower and upper longitudinal beams are also T-section profiles, with heights of h = 75 mm and h = 100 mm, respectively, and widths of t_f = 7 mm and t_w = 14 mm. The cross sections shown in Figure 2 have axes 1 and 2 that help to orient them in the 3D geometric model.

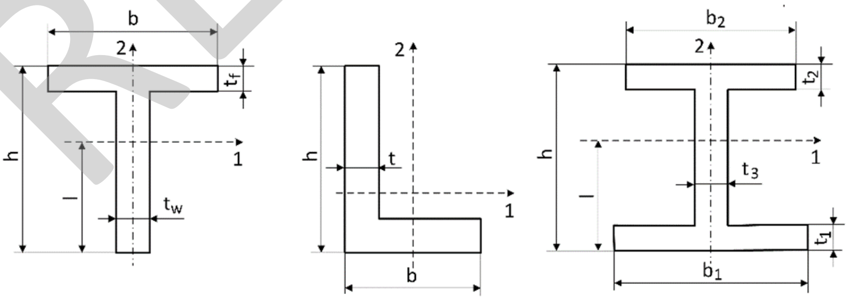

Figure 2
Cross sections of the members of the truss framework

The upper beams of the two portal frames, made from I-section structural steel, have a height of h = 200 mm, while the columns of the portal frames use stronger I-section beams with a characteristic height of h = 315 mm. The wind bracing trusses are formed from L 50×50×6 angle profiles. The truss columns have a more complex cross-section, consisting of multiple adjacent steel profiles. For analysis, these are approximated with an equivalent rectangular cross-section (h = 127.08 mm, b = 23.43 mm) exhibiting identical cross-sectional properties, as determined through simplified manual calculations.

Certain portions of the horizontal members include reinforcements from prior uses, but stiffeners were not modeled. Thus, these beams are assumed to possess uniform profiles in the three-dimensional structural model. Similarly, weather-related damage and corrosion of the structure were disregarded, as their effects were not considered significant factors influencing the mechanical properties of the structure.

This design can be used for open-pit mines where the distance between the banks of an open-pit mine is below 18–20 meters and the span of the bridge cannot be increased without significant modifications opposite the modular design. When a crane of sufficient capacity is available, the entire bridge structure together may be lifted on to take the right place.

The commercial solution is based on a Bailey bridge, which is a portable, prefabricated, modular truss bridge designed for quick assembly without heavy equipment. Figure 3 illustrates the conceptual design of a pre-assembled segment of the alternative modular bridge structure. The available in predefined manufacturer size increments of modular bridge and its components are picked from tables or catalogs tailored to list the various geometric properties, allowing the selection of mobile components with the required conveyor belt width. For a conveyor belt not exceeding a width of 3 meters, a suitable modular variant is also available, for example in Arcow 700XS technical handbook. Due to the conveyor belt width, the modular bridge element in Figure 3, which provides the roadway width and supports the conveyor platform, can be 3.67 meters in width according to the catalog. This available configuration allows sufficient space for an inspection walkway alongside the conveyor belt.

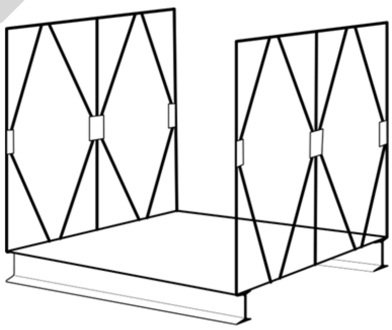

Figure 3
Design of assembled modular bridge elements

The modular bridge structure is assembled from prefabricated modules using detachable bolted connections or pins to mix and match the appropriate components creating the bridge. The bridge construction process can be assembled on site, where the bridge structure is built from one side by continuously adding and connecting pre-assembled modules, extending as a cantilever to reach the opposite support point. The standard truss configurations used for stiffening the bridge can be arranged in multiple rows alongside the bridge platform, thereby enhancing the load-bearing capacity.

3. COMPARISON OF STRUCTURES

The existing structure in Figure 1 meant for reuse is subjected without loading in the first load case (in load case A), i.e. without an installed conveyor belt system. In load case B, the loading is calculated based on the mass of the material transported on the conveyor belt, assuming a loose bulk density of $\rho_h = 1.4\times10^{-9}$ t/mm^3, as described in Ladányi (2018) and Ilic et al. (2017) with the specified material cross section. In load case B, based on Ladányi (2018), a continuous operational load is considered constant, accounting for the weight of the transported overburden rock, the conveyor belt, and associated framework elements, which is evenly distributed across the lower longitudinal beams. The load, calculated using the loose bulk density, is applied at the connection points of the lower cross-braces, distributed as downward forces of 15 kN at nine nodes on each side of the structure between the supports. The total load of 270 kN is represented by small downward vectors, as shown in Figure 4, indicated accordingly.

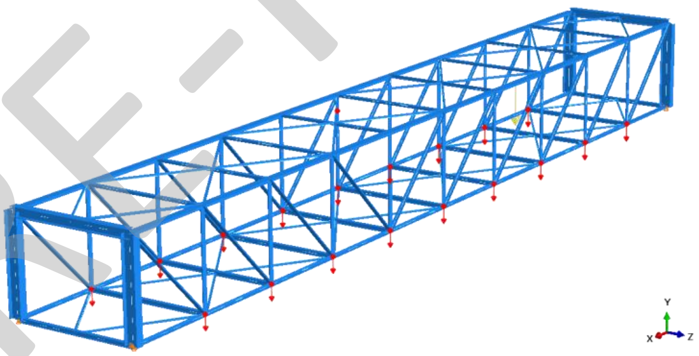

Figure 4
Distribution of loads and supports specified for welded bridge frames

The lateral planes of the conveyor belt intended for installation occupy nearly the entire width of the bridge framework, precluding the possibility of integrating a walkway within the truss structure for inspection purposes. One solution to ensure accessibility is to install a walkway on one side of the structure, supported by cantilever brackets. This configuration has proven effective in other operational mining equipment, such as bucket-wheel excavators, bucket-chain excavators, and spreaders. Due to the additional mass of the cantilever-mounted walkway on the truss structure, a slight increase in weight is introduced compared to load case B. This is addressed in calculation variant C by increasing the applied partial forces by 1.5 kN at the nine loading points on one side. Consequently, a uniformly distributed load of 148.5 kN acts on one side, while the other side retains a load of 135 kN.

Standard material properties for steel are assumed to be isotropic elastic, for which Young's modulus of $E = 2.1\times10^5$ MPa, Poisson's ratio of $\nu = 0.25$, and density of $\rho = 7.85\times10^{-9}$ t/mm^3 are given. Using finite element analysis, the dead weight of 6217 kg is obtained from the 3D beam structure and the specified density.

In the FEA using Abaqus 6.13, the boundary conditions for the first bridge structure were simplified supports at the four lower corner points to prevent rigid-body motion in space while avoiding over-constraint between any two support points. To achieve this, one support point was modeled as a spatial pinned support, constraining motion in all three directions, while the remaining three lower corner points were defined as spatial roller supports, allowing movement within their respective planes but restricting motion perpendicular to those planes. All specified supports permit rotational freedom about the three orthogonal axes.

The conveyor bridge is significantly reinforced at both ends by robust portal frames, which consist of considerably heavier I-beams compared to other elements. The calculations demonstrate that these portal frames substantially enhance the structure's robustness, both in terms of strength and vibrational properties.

In load case C, the asymmetric loading introduces torsional stress in addition to a slight increase in load magnitude on the three-dimensional structure. However, this does not result in significant changes in the strength analysis outcomes.

Modelling the static behavior of the structure is essential for the reusable welded framework. Since effective stresses in the main load-bearing elements occur below 89.86 MPa and the structure is made of grade S275 steel with a minimum yield strength of 275 MPa, the ratio, the actual safety factor for static loads in all three load cases (A, B, and C) exceeds $n = 3$. The maximum deflection at the midspan of the bridge is only 21.6 mm. The primary load-bearing members are the central sections of the lower longitudinal beams and the first cross-braces at the portal frames, as reported by Szirbik et al. (2023).

The loads acting on the conveyor belt during material transport can be determined through measurements or simulations based on the sag ratios of the bulk material and the belt, as described by Ilic et al. (2017). These allow for the calculation of the loads transmitted through the conveyor rollers to the framework due to material transport. The condition monitoring of conveyor rollers can also be achieved using acoustic sensors, as reported by Wijaya et al. (2022).

For simplicity, a 3D wireframe in Abaqus with beam elements was used for the modal analysis, neglecting damping to predict the natural frequencies and mode shapes of the structure. The natural frequencies are arranged in ascending order, summarized in Table 1 for load cases A, B, and C. If the suspended hanging roller sets are applied, the forces resulting from the loads are exerted in the vertical direction, uniformly distributed, at the midpoints of the piers, and considering an angle of the wing rolls of 30^{o}, the perpendicular components also arise. The maximum value of the vertical displacement is 23.15 mm in the middle of the bridge; thus, the deflection ratio remains 0.01%. The results indicate that the structure is excitable at relatively low frequencies, a consequence of using slender members. Although the structure is subjected to loading, this has a minor impact on its vibrational behavior, as the primary load-bearing elements are the central sections of the lower longitudinal beams and the first cross-braces at the portal frames, as noted by Szirbik et al. (2024).

Table 1

Natural frequencies [Hz] for load cases A, B, and C

Modus No.	**Load cases**		
	A	**B**	**C**
1.	7.727	7.702	7.701
2.	9.285	9.285	9.284
3.	10.095	10.146	10.149
4.	14.480	14.477	14.476
5.	14.738	14.560	14.548
6.	16.004	15.405	15.361

It can be concluded that the applied loads do not significantly detune the structure, only slightly modifying the natural frequency values, as the preload in most structural members changes minimally. The linear perturbation performed on the FE model yields the natural frequencies, but the first few modes are dominant and are necessary for further analysis. Structural damage or deviations from the designed parameters can lead to changes in the natural frequencies, which may have unfavorable consequences.

The modular bridge's truss construction contains eight bays, resulting in a nominal span of 24.4 m, and can be substituted for the welded structure. Considering the roadway width of 3.67 m and the height of 1.74 m, the dead weight of the bridge is 16224 kg. Concluding that the selected modular design weighs more than the first welded version, which needs to be modified. The selected bridge designs can be reinforced by adding additional components. The modular bridge can be reinforced more easily with double-storey or two-panel tower constructions. The adequate load-bearing capacity and stability in the truss construction, associated with the conveyor belt system, can be ensured based on the technical specifications provided in the manufacturer’s solutions published in the manufacturer's catalogs. The existing structure in Figure 1. meant for reuse can be damaged from the overloading and, etc. must be continuously monitored, which is why a sidewalk is also placed on the bridge on one side along the conveyor belt. Modular designs provide sufficient space for monitoring and are more resistant to vibrations caused by the movement of the conveyor belt than the welded truss structure.

4. Conclusions

A truss structure designed and built for the conveyor belt transporting lignite is reused for a new belt conveyor system, which applies a wider belt than the previously installed unit, and the total weight of the belt conveyor increases. The options included the reconstruction or use of a Bailey bridge-based commercial solution, which is a portable, prefabricated, modular truss bridge.

Finite element simulations on the three-dimensional wireframe model of the reusable bridge framework provide accurate insights into structural deformation and stress distributions, as well as the extraction of natural frequencies in the modal analysis. The FEA is essential for the preliminary verification of operational safety for the conveyor belt system installed on the truss bridge structure.

Finite element simulations for the existing structure have proved that the truss bridge is robust enough for the new conveyor belt and the material being transported is adequate based on the deflection and safety factor. Furthermore, the I-beam gates at the ends also strengthen the structure.

The conveyor belt system monitoring and the unexpected vibrations cause problems with the reuse of the truss structure. The investigation of vibrations induced by the conveyor belt motion and roller wear on the truss structure is unavoidable, as resonance must be prevented. The modal analysis provides the basis for investigations of excited vibrations to mitigate vibration-related issues in structures.

We have found that the weight of the optional modular design exceeds that of the existing welded structure, and bank abutments must also be constructed accordingly. But the advantages of the modular structure are also obvious, particularly in the combinatorial possibilities of the components, allowing the panel bridge to be reinforced with additional components if necessary, forming double-storey or two-panel tower constructions.

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