ENGINEERING NOTE

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Program - Project - Job: DesignWorks - Rock Trolley – Structural Design Factors

Title: Design of Rock Trolley Structure with ANSYS Structural Stress Analysis

The rock trolley structure is comprised of four heavy duty machinery dollies supporting three parallel box beams, which are orthogonal to and support five parallel I-beams. These I-beams support a ½" steel plate with patterned rectangular cutouts. A Unistrut frame attaches to the structure at the trolley's leading edge.

The two layers of box and I-beams support two-axis bending from the rock's six-ton payload. The top plate distributes the payload weight to these beams, and partially supports torsional loading that can arise from out-of-plane machinery dolly displacements. Two of the machinery dollies are fixed and two swivel for steering; each has a manufacturer's list capacity of 7500lb.

The payload rests atop the plate on a 0.5-inch thick neoprene rubber padding that can be cut into for underbelly access to the rock through the patterned cutouts. The neoprene hardness is 50 durometer. A Unistrut frame mounts forward of the trolley body and provides both forward support and tie down locations for the payload over the trolley's short travel distance.

Four hydraulic cylinders are attached to the bottom of the pallet at the center of each edge. These cylinders act to lift the pallet against the rock and provide support while the rock is cut out of the tunnel wall. No electrical power is required as the trolley's hydraulic lift system is entirely manually operated, and the trolley's movements are unpowered.

A finite element analysis of the rock trolley was conducted to determine the stress levels in the structure during operation. ANSYS was used for the finite element analysis; it is one of the industry standards for structural finite element analysis. The analysis model geometry is assumed to be a continuous lumped solid comprised of the box and I-beams and the top plate. A single 10-node tetrahedral structural solid element type is used throughout.

Figure 1 shows the design load-- a uniform pressure of 17psi applied to the plate's crosshatched surface. This pressure is the rock payload weight of 12000lb divided by the plate's surface area. This loading condition is an approximation of the actual loading condition; although highly fractured, the rock still provides some level of self-support and does not maintain an even pressure loading on the top of the pallet (as a liquid would).

The structural analyses were performed on box beams of three wall thicknesses: 0.25", 0.375", and 0.5". The quarter-inch wall thickness beams were not enough to satisfactorily reduce plate stress below yield when supported at only 3 dolly locations, and half-inch thickness beams were adequately stiff but added unnecessary weight.

The next three figures show von Mises stress results for the 0.375" box beam design in each of the three support conditions that were analyzed. The first condition (Figure 2) is when the trolley is lifted off the ground by the hydraulic jacking system. These slave cylinders are located on the trolley's lower perimeter, intermediate between machinery dollies.

The second figure (Figure 3) shows the result for when the trolley has all four machinery dollies supported from below. The analysis assumes all four machinery dollies are lying on the same plane. During actual use, it is more likely that one of the four machinery dollies lies higher or lower than the other three (since the ground is most likely not completely flat).

Finally, Figure 4 shows stress results for the possible case where only three of four machinery dollies contact the ground coincidentally. Here, the unsupported fourth machinery dolly's interface block is left attached to the structure in the model, thereby providing a marginal contribution to the local stiffness. This condition is the worse case scenario (the fourth machinery dolly does not even touch the ground). We expect that most conditions will be somewhere between all four machinery dollies providing support on a level ground, to only three machinery dollies supporting all the weight. Placing the rock pallet on as level a ground as possible will minimize the stress levels. The analysis indicates that if the fourth machinery dolly is providing no support, the pallet will deflect 0.36 inches out-of-plane. We recommend checking that the flatness of the ground or floor under the trolley is less than 0.36 inches to minimize the stress on the pallet when it is fully loaded. Stress levels may increase to extreme levels if a fully loaded pallet is rocked back and forth on only three machinery dollies.

The largest von Mises stress levels for the box beam design are shown in Figure 5, corresponding to the support case where only three of four machinery dollies are supporting the entire payload weight. Even in this worst case condition, the plot shows that the highest stress levels in the plate are between 20-25ksi, below the minimum yield strength of 36ksi for A36 steel. And the plot's highest stresses of just over 37ksi occur in highly localized regions at the intersections between box and I-beams, where a 0.375-inch fillet weld is specified.

Since the finite element model as shown in Figures 1 to 5 did not accurately represent the weld (the model has a sharp corner), a second analysis was conducted with the weld more accurately modeled to verify that the stress condition is tolerable. Figure 6 shows the stress results at the weld location for a bending of 0.36 inches in the rock trolley (one machinery dolly is 0.36 inches below the other three). Although the maximum von Mises stress at the weld location shown in the figure is slightly higher than the yield strength (38ksi), the stress location is highly localized and after a small amount of local yielding the weld joint strengthens. However, whenever welds are critical to providing support (as is the case here), the user should regularly check the welds for cracks to ensure they have not failed.

Although the Figure 5 plot doesn't indicate stress concentrations in the plate's square hole corners, half-inch corner radii were included in the fabrication drawings as an added measure of safety.

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Table 1: Trolley Characteristics

Overall length	48”
Overall width	48”
Height *w/out Unistrut frame*	13”
Gross weight	750lb
Max payload capacity	12,000lb
Max hydraulic operating pressure	1700psi @ Max Cap.

Table 2: Analysis Features

Number of elements	27459 (model in Figs 1-5) 58181 (model in Fig 6)
Material Property: Modulus of Elasticity	30e6 psi (both models)
Material Property: Poisson’s ratio	0.3 (both models)
Coordinate system	Y = vertical X = parallel to upper I beams Z = parallel to lower box beams
Boundary conditions	UX, UY, UZ = 0 at one machinery dolly location UX, UY = 0 at second machinery dolly location (attached to same box beam as first location) UY = 0 at third machinery dolly location

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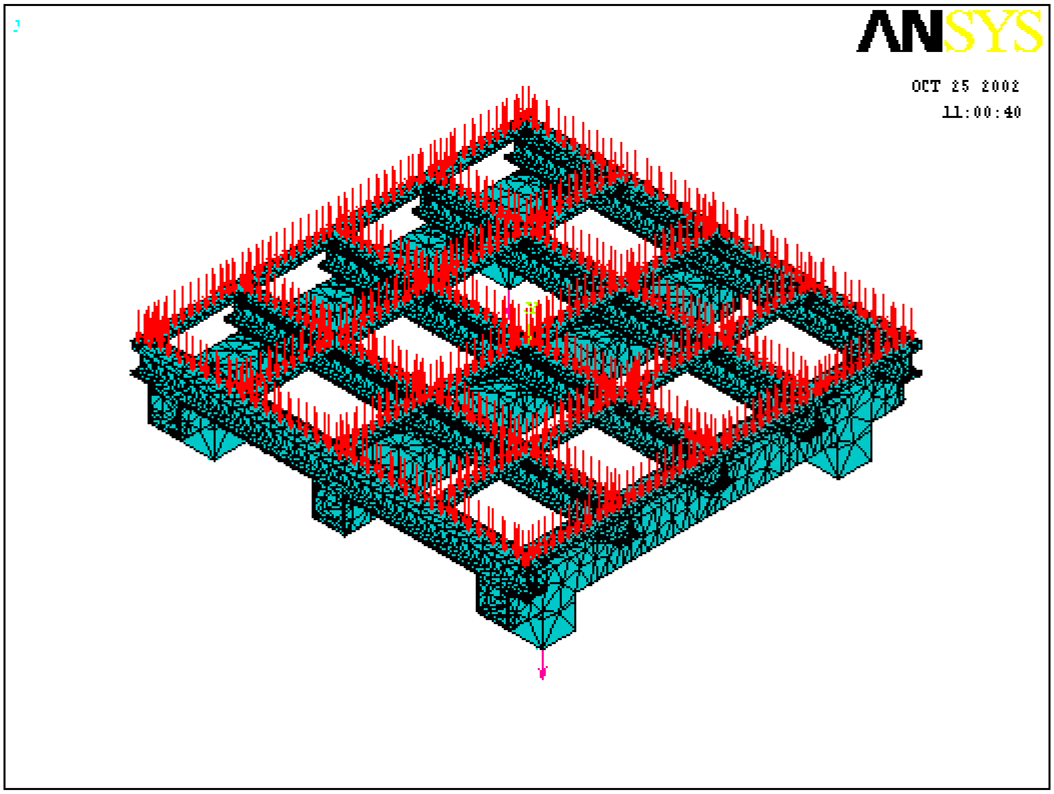

Figure 1. Finite element model showing all 27459 elements. Vertical arrows indicate pressure load uniformly applied to the plate's crosshatched top area.

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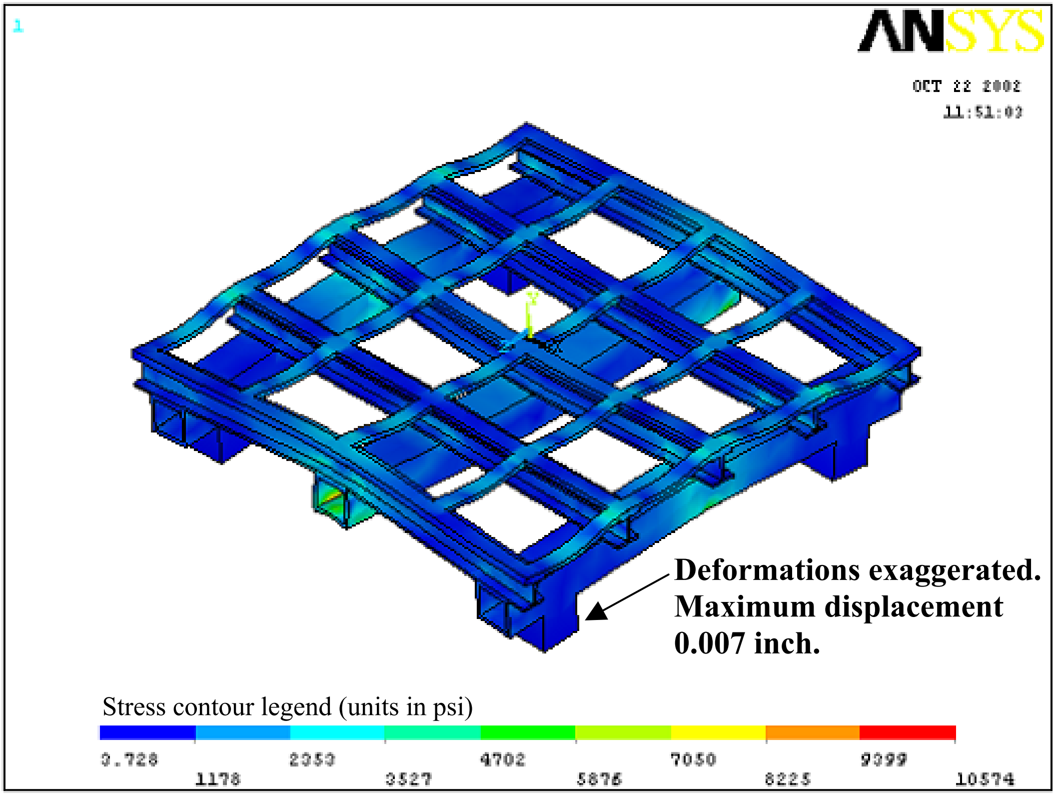

Figure 2. Stress plot for 0.375” box beam design when supported on all four hydraulic cylinders (not shown).

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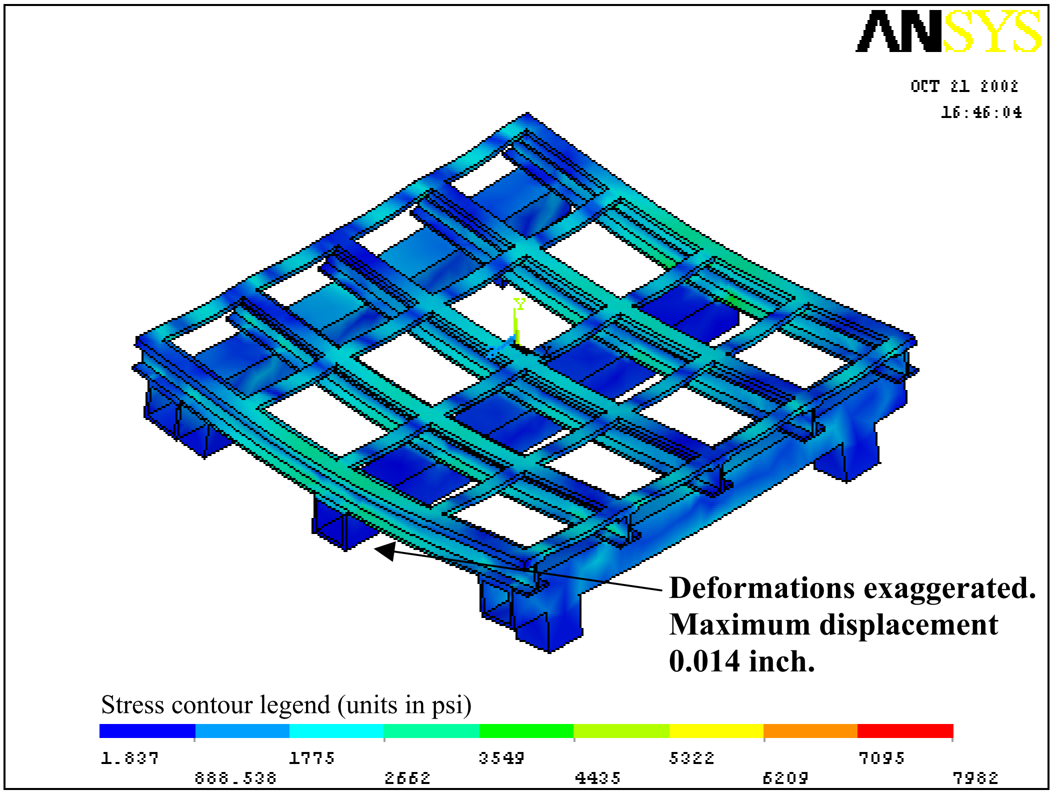

Figure 3. Stress results for design with 0.375" box beams when supported on four machinery dollies (modeled as steel blocks at each corner).

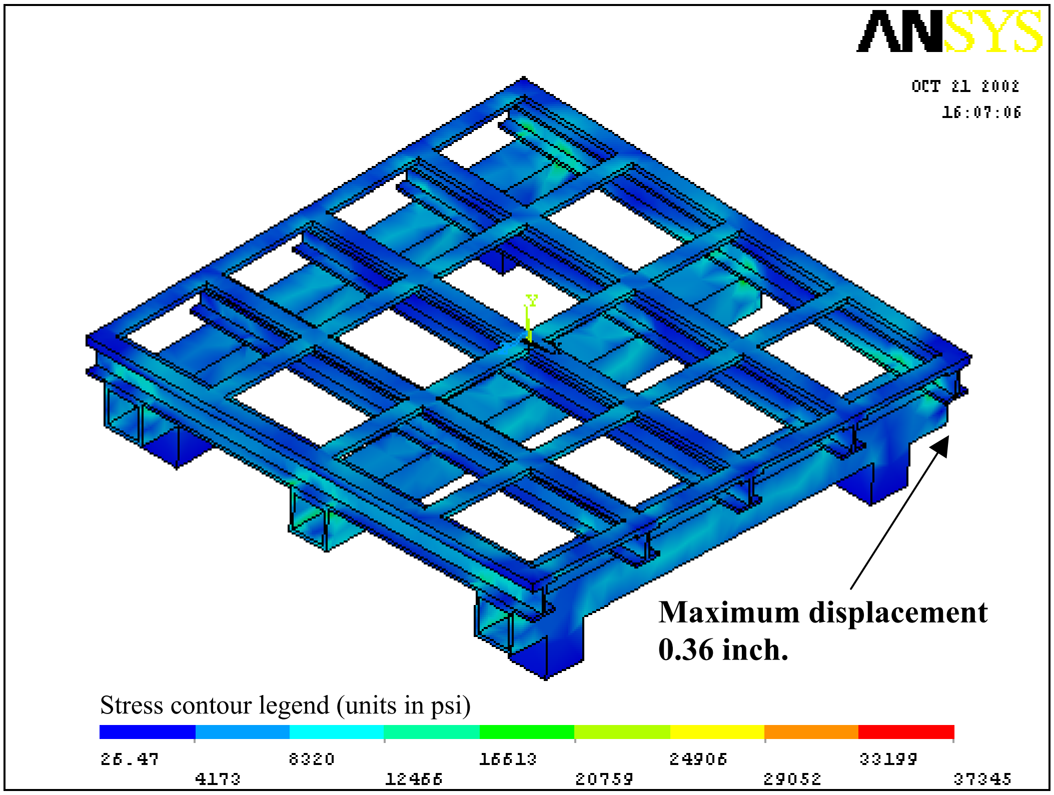

Figure 4. Stress plot for design with 0.375” box beams when supported on only three of four machinery dollies.

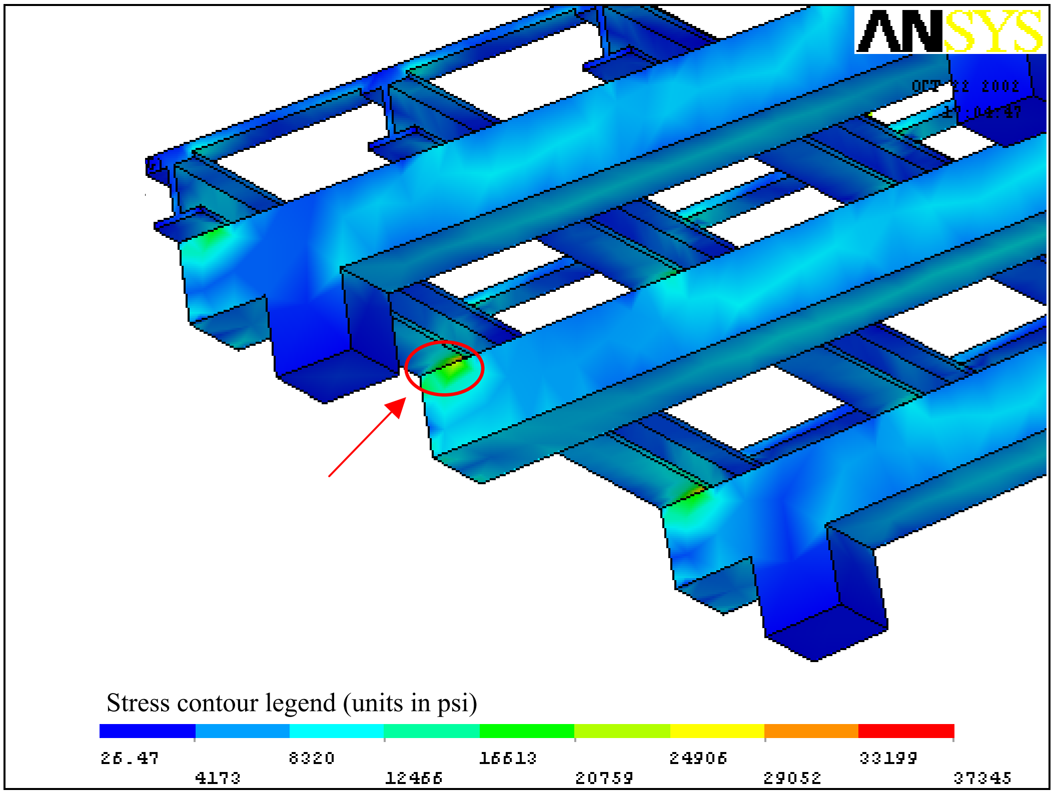

Figure 5. Magnified bottom view of stress plot shown in Figure 4. Arrow indicates maximum von Mises stress location at interface between box and I-beams.

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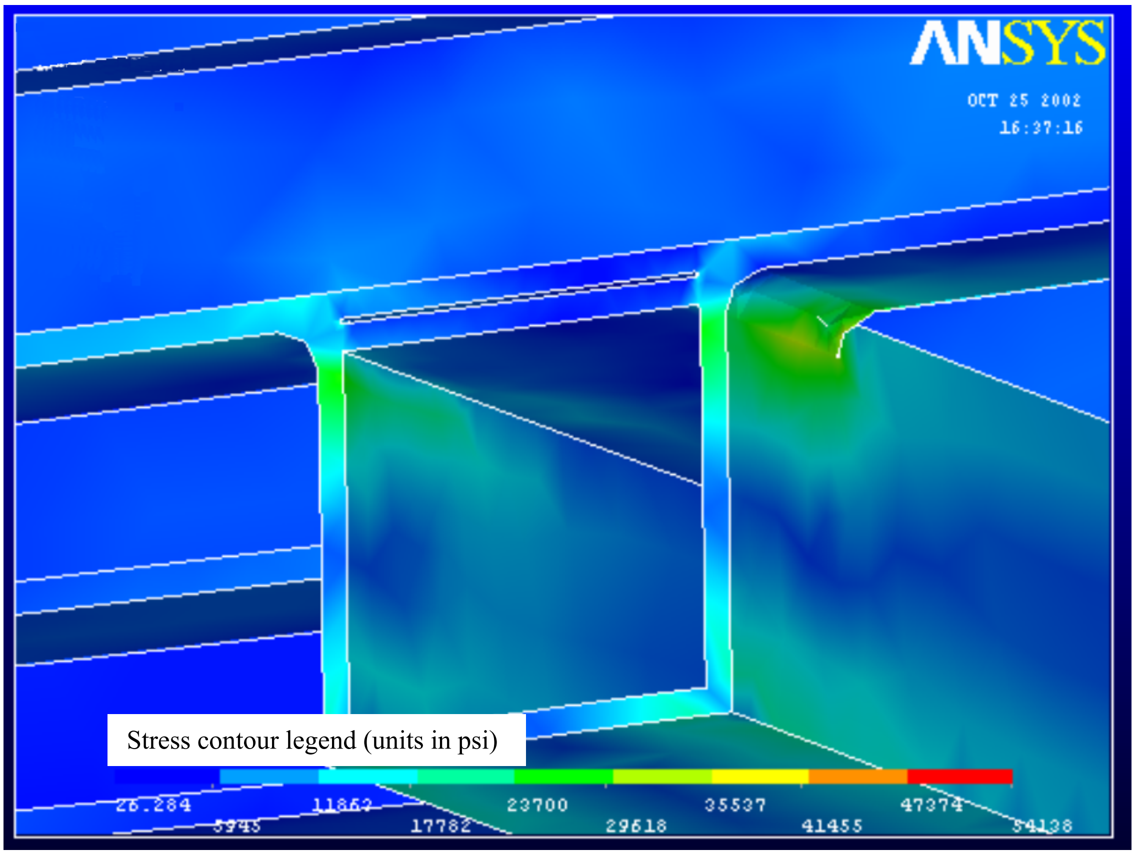

Figure 6. Analysis with weld detail (at box beam to I-beam welds) showing von Mises stress values of 38 ksi.