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Autor: Harris, Robert / Valley, Michael

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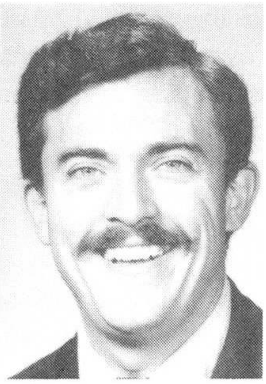
Evaluation, Repair, and Maintenance of a Mobile Conveyor

Évaluation, réparation et entretien d'un transporteur mobile

Überprüfung, Instandsetzung und Wartung einer fahrbaren Bandanlage

Robert HARRIS
Principal
J.R. Harris & Company
Denver, CO, USA



Jim Harris has designed or evaluated hundreds of structures including industrial facilities, long span structural floors carrying exceptional loads, buildings in the highest seismic zones, excavation bracing, pile and pier foundations, and historic renovations.

Michael VALLEY
Project Engineer
J.R. Harris & Company
Denver, CO, USA

Mike Valley has experience in engineering design and evaluation for residential, commercial, industrial, and institutional structures in steel, concrete, wood, and masonry. He has performed fatigue and seismic structural analysis of complex structures.

SUMMARY

The paper describes the inspection and analysis procedures used to evaluate and strengthen a space truss mounted on crawler treads. The structure had experienced distress related to its static strength and its fatigue resistance. Care was taken to calibrate the analysis to actual performance. Evaluation criteria were tailored to the specific con-ditions of this structure by modifying a modern load and resistance factor design stan-dard. A program of systematic inspection for and repair of fatigue cracks was instituted.

RÉSUMÉ

L'article décrit les méthodes d'inspection et d'analyse employées pour le renforcement d'une charpente métallique montée sur chenilles. La charpente avait donné des signes de faiblesse tant aux sollicitations statiques qu'à la fatigue. L'analyse a été soigneusement comparée au comportement réel. Les critères d'évaluation ont été adaptés aux condi-tions spécifiques de cette charpente en modifiant un règlement moderne aux états limites. Un programme systématique de contrôle et de réparation des fissures a été mis en place.

ZUSAMMENFASSUNG

Der Beitrag beschreibt die Prüf- und Berechnungsverfahren, die bei der Verstärkung eines räumlichen Fachwerkträgers, der auf einem Raupenfahrwerk montiert ist, eingesetzt wurden. Die Konstruktion wies Schäden bezüglich ihrer statischen Tragfähigkeit und ihres Ermüdungswiderstandes auf. Das Rechenverfahren wurde sorgfältig am gegenwärtigen Tragverhalten kalibriert. Die Ueberprüfungskriterien wurden für den speziellen Fall aus einer modernen Norm mit Teilsicherheitsbeiwerten abgeleitet. Es wurde ein Programm für die systematische Inspektion und Reparatur von Ermüdungsrissen aufgestellt.

1. INTRODUCTION

The Round Mountain Stacker is a mobile crawler-mounted stacker that builds a gold ore pile for cyanide process leaching at the Round Mountain Gold Mine. Within three years of construction, the mine personnel noticed some cracking and excessive deflections. A preliminary evaluation revealed that fatigue and overstress were of concern.

Due to the importance of the stacker in mine operations, a much more detailed level of inspection and analysis was undertaken. Inspections were intended to identify potential problems, classify structural details for fatigue resistance, accurately quantify the magnitude and cyclic load history of important loads, and obtain information which could be used to calibrate the analytical model.

The analysis efforts focused on quantifying the static stress levels and stress ranges experienced by the structure, establishing appropriate strength and fatigue evaluation criteria, and using these results to identify structural members and/or details which would require repair or more frequent inspection. Based on the inspection and analytic findings, repair and operational recommendations were made.

2. DESCRIPTION OF STRUCTURE

The stacker consists of a 90 m long bridge that is mounted on crawlers and a tripper that rides rails on the bridge (See Figure 1). The stacker is a 3-dimensional space truss composed primarily of wide flange and angle rolled shapes, made of A36 steel. Some of the members have additional cover or doubler plates welded to them. Nearly all of the connections are fully welded. There is a luffing boom at the tail (feed) end of the stacker that is composed of structural tees and angles.

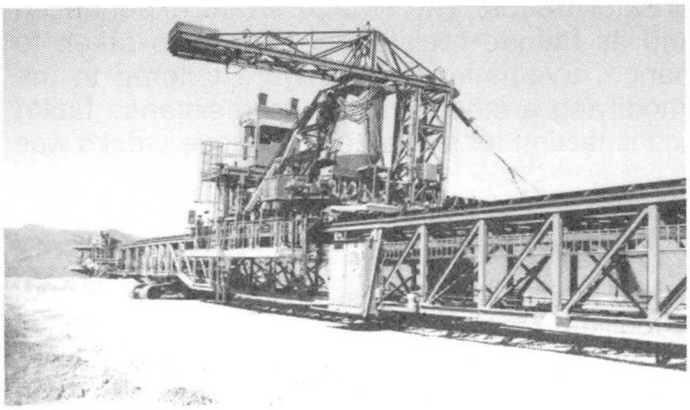


Figure 1 - Stacker and Tripper Car

Because the structure is a space truss, the bending moments are generally relatively low. However, the rails on which the tripper rides are directly attached to the top chord. Therefore, when the tripper wheels are between truss panel points, fairly large moments are induced in the top chord.

The fatigue resistance of connection details is generally inversely proportional to the severity of stress concentration. Many of the details used in this structure cause fairly large stress concentrations and have a correspondingly small allowable stress range for fatigue. In several of these areas, cracking consistent with fatigue was already evident. Most of the fatigue cracks were at the connections of secondary members. However, there were cracks approaching 40 mm long in the flange of the bottom chord members at midspan; rapid propagation of these cracks would have led to total failure.

3. INSPECTION

Our preliminary inspection of the stacker and tripper led us to believe that the tripper's weight was not equally distributed to its wheels. The complexity of the tripper framing and large amount of additional plate steel made accurately calculating tripper weight unfeasible. Since the tripper is the primary load on the bridge, and by far the most important contribution to fluctuating member stresses, an accurate determination of its overall weight and the distribution of this weight to its wheels was necessary. A field weighing of the tripper was carried out by jacking between the rail and the tripper undercarriage near each wheel using a calibrated hydraulic ram. To assure valid results, measurements were taken with the tripper boom slewed at three different angles, and with the tripper located over a support and at midspan of the stacker. The overall tripper weight was about 565 kN, which is considerably more than our preliminary estimates. The results were incorporated in our final analysis of the stacker.

In order to calibrate and confirm our analytical model, a deflection survey was undertaken by mine personnel. The survey results in the form of north, east, and elevation coordinates for several points along the bridge with the tripper in various positions were reported to us.

The analysis predicted that some localized yielding should have occurred in some members, particularly over the supports. Such yielding would cause a noticeable sag of the cantilevered ends of the stacker, which was noted during preliminary inspections and was measured in the deflection survey. The permanent deflection set in the structure is consistent with analytical predictions.

Since some fatigue cracks had already been found in primary structural members, a much more careful inspection of fatigue susceptible connections was made using the dry magnetic particle method. This careful inspection was also used as a vehicle by which mine personnel were taught how to perform periodic inspections for strength and fatigue problems.

4. ANALYSIS

4.1 Basic Model

A linear-elastic member analysis of the stacker was performed using a general purpose 3-D structural analysis program called SAP90. The member properties specified in the analysis match the properties of the members on the actual structure, which in many cases had been field modified by the addition of cover and/or doubler plates. Since the connections in this space truss were fully welded, the members were modelled using frame elements which can resist axial force, torsion about the longitudinal axis, and shears and moments along the major and minor section axes. In locations where the physical connections of the structure do not allow the transmission of certain of the frame forces, member degrees of freedom were appropriately released so as to prevent these forces from developing.

Dead loads are those loads which are known fairly accurately and are considered permanent, although some of these loads may potentially be moveable (as in the case of the tripper weight). By far, the most significant loads on the structure come from the weight of the tripper. In addition to tripper weight, the dead loads included member self-weight and the weight of drive motors and pulleys, electrical cabinets, rails, conveyor belts, idlers, drive chain and power cable, conduit, and ore spillage on the structure.

Live loads are those loads which are produced by the use of the structure and they are typically known with less certainty than dead loads. On this structure the live loads are limited to those loads produced by the ore payload and by belt tensioning. Wind loads were resolved into distributed loads on the top and bottom chords of the bridge for wind on the members of the bridge, and point loads at the tripper wheels for wind on the tripper. The wind on the tripper causes essentially equal loads at the wheels in the direction of the wind, and vertical forces that resist the overturning of the tripper.

In order to prevent spurious tension at the soil-structure interface, and to allow the redistribution of loads by differential support settlement, the supports were modelled using linear-elastic springs for translation degrees of freedom. Spring constants were adjusted during model calibration as noted below.

4.2 Calibration

Two bases were used to establish the stiffness of the vertical soil springs. The first basis was to use the stiffest spring that produced no net tension on a crawler for any load condition. The second basis was to compare that soil spring with geotechnical information for subgrade stiffness. The vertical soil spring stiffness used was consistent with a subgrade modulus of 13600 kN/m^3, which is reasonable for an uncompacted fill. Longitudinal and transverse soil springs were made just stiff enough that the computed reactions did not indicated slipping.

The considerable care taken in member, load, and support modelling, resulted in structural response which met the analysis objectives and was fairly consistent with the measured response.

4.3 Processing Results

An analysis post-processor, called faSAP, was developed for this project to assist in a determination of the stresses and stress ranges experienced by individual members of the structure.

This post-processor reads the SAP90 input file, which defines the structural model, including member connectivity, orientation, and properties. It then reads a user supplied file which specifies the fatigue load condition (number of cycles) and the allowable compressive and tensile stresses, associates an AISC fatigue category with each member, and optionally provides ratios by which the area, and section moduli may be adjusted for fatigue stress determination (such as at the end of a cover plate). Then a binary file containing the member forces for each combination of loads considered is read, and axial and bending stresses are calculated and combined. For each member, the stresses are calculated at each end and at three intermediate sections (quarter and midpoints). At each section, the stresses are calculated at the four extreme corners of the section. The minimum and maximum stresses which occur at any points in the member and the maximum stress range experienced by a given point of the member are calculated. The experienced stress range is compared to the stress range allowed for each member based on its fatigue category.

This post-processor produces three forms of output. The primary output is a text file which presents the fatigue stress analysis results for each member. For each member, this file indicates the minimum and maximum stresses and the load cases that produce them. The maximum stress range experienced at any point and the load cases which define the extremes of the range are output along with the section (of the five sections checked) and the location on that section where the maximum stress range occurs. Members which fail to satisfy the strength and/or fatigue evaluation criteria are flagged. The second form of output is a DXF (AutoCAD compatible) file which shows three plots of the structure, with its members color-coded to indicate the most severe stresses, maximum stress range, and comparison of calculated stress range to the allowable stress range for fatigue. The program also writes spreadsheet files which may be used for graphing the overall member force, stress, and stress range trends for the structure as a whole.

5. EVALUATION CRITERIA

5.1 Static Strength

Rather than making strict use of conventional standards in evaluating the structure, maximum stress criteria specifically suited to this structure were developed. The *Load and Resistance Factor Design Specification for Structural Steel Buildings* was used as a base reference [1]. This standard was chosen as a basis because it includes a clear exposition of the true capacity of structural steel members and systems, which does not vary by type of structure or engineering process, and because it provides safety levels that depend upon the degree of uncertainty in loads, structural material strength, member and system tolerances, and analytical and behavioral models. The conceptual advantages of strength-based design in evaluation of existing structures is well established.

The load factors used in the *LRFD* for dead, live, and wind loads are 1.2, 1.6, and 1.3, respectively. These factors are based upon statistical reliability analyses for ordinary building construction. For this project, the tripper weight is by far the most significant load causing stress, and that weight is known quite precisely. For the total mobile conveyor, the tripper dead weight is 35% of the total dead plus live, with the truss self weight being 31% and the distributed dead load being 17%. Live load, which is primarily the ore on the two belts, is only 17% of the total. When considering stress at any point, the tripper dead weight is an even larger fraction of the total, because only about half the truss weight and distributed dead load is really effective in increasing the stress in any single member. These considerations led to a reduction of the load factor for dead loads from 1.2 to 1.1 for this structure, because of the weighing done on the tripper. Similar considerations allowed a reduction of the load factor for live loads from 1.6 to 1.4 because there is much less uncertainty about the weight of ore on the belt than there is with conventional live loads on buildings.

The resistance factors used in the *LRFD* for axial compression, axial tension, and bending are 0.85, 0.90, and 0.90, respectively. There are many issues that enter into establishment of these factors. For this evaluation, each resistance factor was raised by 0.05 to account for the past inspections of the structure and the ability to continue easy inspection in the future due to the exposed nature of the structure. Another reason for the increase is the calibrated analysis, which is somewhat more precise than would be used in ordinary design.

The revised load and resistance factors were used to develop modified allowable stresses for flexure, tension, and compression, against which the computed stresses were compared. The fact that the load and resistance factors developed for this project allowed a smaller margin of error was taken into account when areas that required strengthening were being chosen.

5.2 Fatigue

The fatigue evaluation undertaken in this study was based on the stress-life, S-N, method which is widely used in high-cycle applications where the applied stress is primarily in the elastic range of the material. This method is based on empirical determination of appropriate constant and exponent in the relation $N \cdot S^k = constant$, for various structural details (where N is the number of cycles and S is the stress range).

This relation plots as a straight line on log-log paper. The constant, and to a degree the exponent, depend on the precise configuration of the structural element. There is a large range in resistance to fatigue, with "clean" elements (those with few or no details creating stress concentrations) being much more resistant than "complex" elements. For any single type of element there is considerable scatter in experimental data, and the allowable stresses cited in standards such as the *LRFD* are considerably below the mean of experimental values. For a given type of structural element, the *LRFD* gives allowable stress ranges for various ranges in the number of cycles of stress. The European standard, *Recommandations pour la vérification à la fatigue des structures en acier* specifies the linear relation on a log-log graph (effectively specifying an allowable value for the constant and the exponent) [2].

The detail classes specified in the *LRFD* were used, but the constant and exponent corresponding to the specified allowable values were calculated to arrive at an allowable stress for the number of cycles expected in the life of this structure. The *Recommandations* specifies an exponent of 3 for fewer than 2,000,000 cycles, and a plot of the *LRFD* values clearly shows that an exponent of 3 is a good fit. Based upon the operation of the structure prior to this evaluation and the recommendations for changes in this operation, 175,000 cycles was used as the desired life to compute the allowable stress ranges.

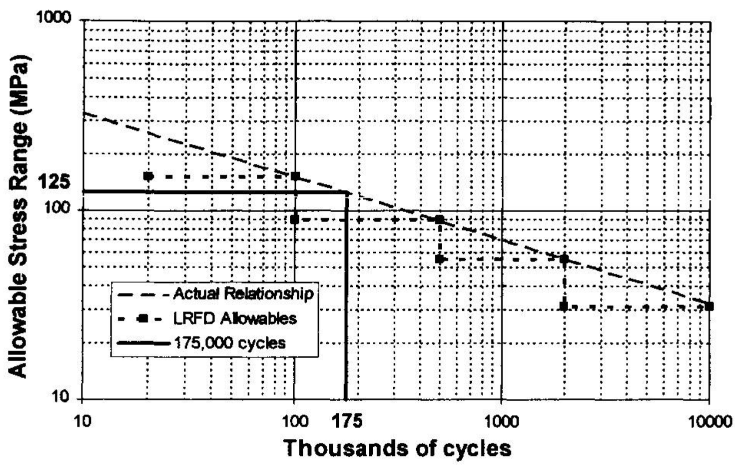


Figure 2 - S-N Diagram for LRFD *Category E*

Figure 2 shows the development of this criterion. This value strictly applies for stress ranges where the maximum stress is tensile and the minimum stress, if compressive, is not larger than the maximum stress. For those members in which the entire stress range is in compression, fatigue is not ordinarily a failure possibility. An exception to this exists in elements or details stressed so highly that yielding occurs; yielding over several cycles will shift the mean stress such that a location that originally experienced only compression will begin to experience tension. Where the compression stress is larger than the tension stress, an artificial stress range equal to twice the tension stress was used for comparison.

6. REPAIR AND OPERATIONAL RECOMMENDATIONS

The evaluation found that the structure had both safety and serviceability problems: some members were significantly overstressed, and many members experienced stress ranges that were already causing fatigue cracks. Repairs were designed and constructed to remedy the locations where static stresses were above the modified allowable value. The repair scheme took into account operational constraints and the isolated nature of the site. It is not feasible to improve the fatigue life categories of the various member and connection details. The concept followed was to schedule detailed inspection at fatigue-sensitive locations on a frequent enough basis so that cracks would be detected and repaired before they reached the critical size to initiate brittle fracture. Lack of detailed information forced this to be based on coarse approximations. An inspection program was developed, which included a training program to instruct mine personnel in visual and dry magnetic particle crack inspection procedures. Standard details were developed for repair of cracks to extend the useful life of the stacker in the face of potential fatigue problems.

REFERENCES

1. AISC, *Load and Resistance Factor Design Specification for Structural Steel Buildings*, American Institute of Steel Construction, 1986.

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