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Collapse of a Cantilevered Truss Supporting a Heavy Crane

Rupture d'une poutre-console à treillis supportant un pont-roulant lourd

Bruch eines Fachwerkkragträgers einer Kranbahn

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SUMMARY
After three years of operation, a cantilevered steel stuss supporting a heavy 1070-kN crane collapsed as a result of fatigue in the anchor bolts resisting the tensile reaction. The tensile reaction was taken by then 51-mm diameter anchor bolts. It was estimated that these bolts were sujected to approximately 370 000 cycles of loading producing an average nominal stress range of 55 MPa. The failure was attributed to uneven fluctuating tension in the bolts.

RESUME
Après trois ans d'utilisation, une poutre-console à treillis métallique supportant un important pont-roulant de 1070 kN s'est effondrée par suite d'une rupture de fatigue des boulons d'ancrage reprenant la réaction de traction. La réaction de traction était reprise par dix boulons de 51 mm de diamètre. On a estimé que ces boulons furent soumis à environ 370 000 cycles de charge produisant une différence moyenne de contrainte nominale de 55 MPa. La rupture fut attribuée à une distribution non uniforme de la tension dans les boulons.

ZUSAMMENFASSUNG
Nach dreijähriger Betriebszeit brach der auskragende Fachwerkträger eines 1070 kN-Krans infolge Ermüdung der Verankerungsschrauben. Die Zugspannung wurde durch zehn Schrauben mit einem Druckmesser von 51 mm aufgenommen. Eine Schätzung ergab, dass die Schrauben ungefähr 370 000 Lastwechsel mit einer nominellen durchschnittlichen Spannungsdifferenz von 55 MPa erfuhren. Der Unfall wurde einer ungleichen Spannungsverbreitung in den Schrauben zugeschrieben.

1. SITE INVESTIGATION

The site of the collapse of a very large cantilevered truss supporting a heavy 1070-kN crane is shown in Fig. 1. At the time of the collapse, about 10:30 A.M., the crane was at the end of the truss, removing oyster shells from a barge. The operator of the crane was killed, and another man working near the barge was severely injured.

The position of the collapsed truss and markings on the debris clearly established that the failure occurred as a result of loss of the tensile reaction. When this occurred, the truss began to rotate about the compressive reaction. This rotation was resisted by the crane rail, which exerted a horizontal pull, causing the pier taking the compressive reaction to fail in lateral bending at its base. As a result, the truss also moved backward and inward, and finally collapsed.

The tensile reaction was resisted by ten 51-mm diameter anchor bolts, arranged in two rows. The picture in Fig. 2 shows how the bolts protruded through a heavy weldment at the support of the truss that did not collapse. A view of the pier where the failure occurred is shown in Fig. 3. Seven bolts may be observed protruding from the pier. The bolts were bent by the impact of the truss, which occurred after the pier failed that was taking the compressive reaction, and the truss began to fall. Two bolts on the near side of the pier were broken below the top surface, apparently from the truss rolling off of the pier. One bolt, on the far side near the column extending above the top of the pier, was fractured in the region where grout had been placed between the weldment and the top of the pier. The surface of this bolt, as well as other bolts, was corroded in this region. There was no evidence of deformation or slip of any part of the anchor bolts embedded in the pier.

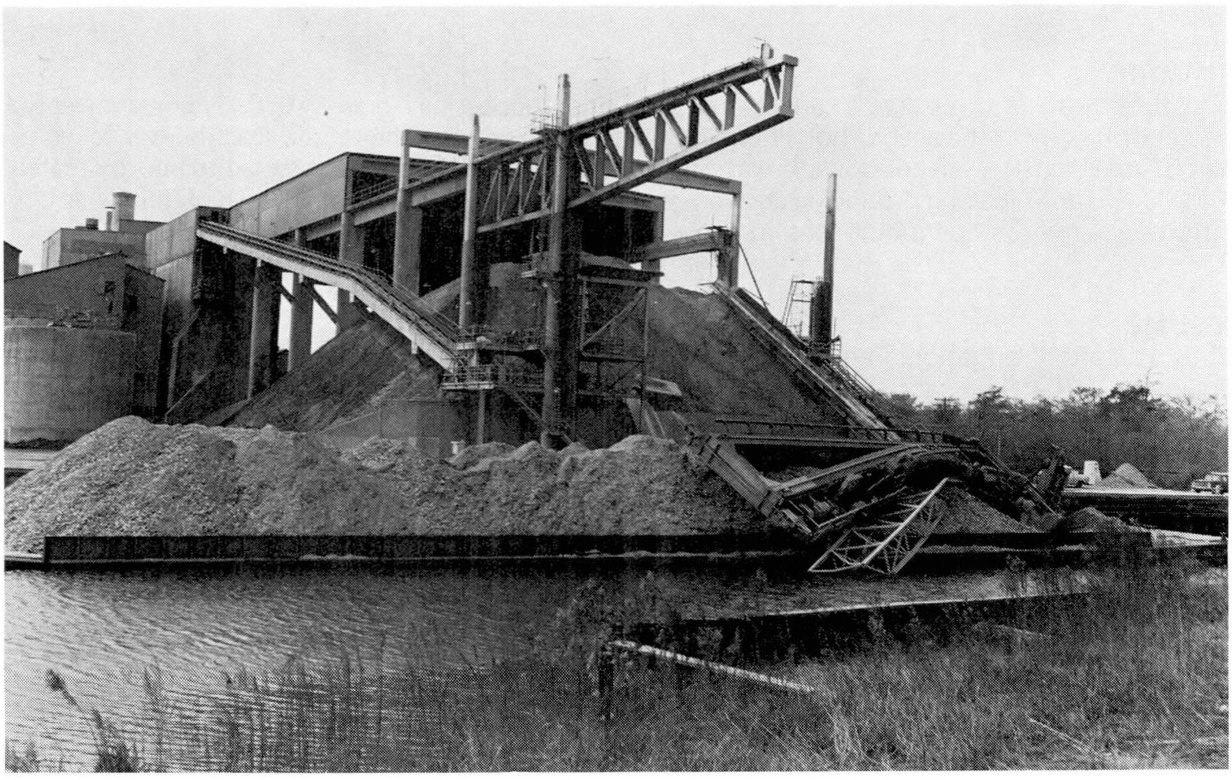


Fig. 1 View of Collapsed Truss and Crane

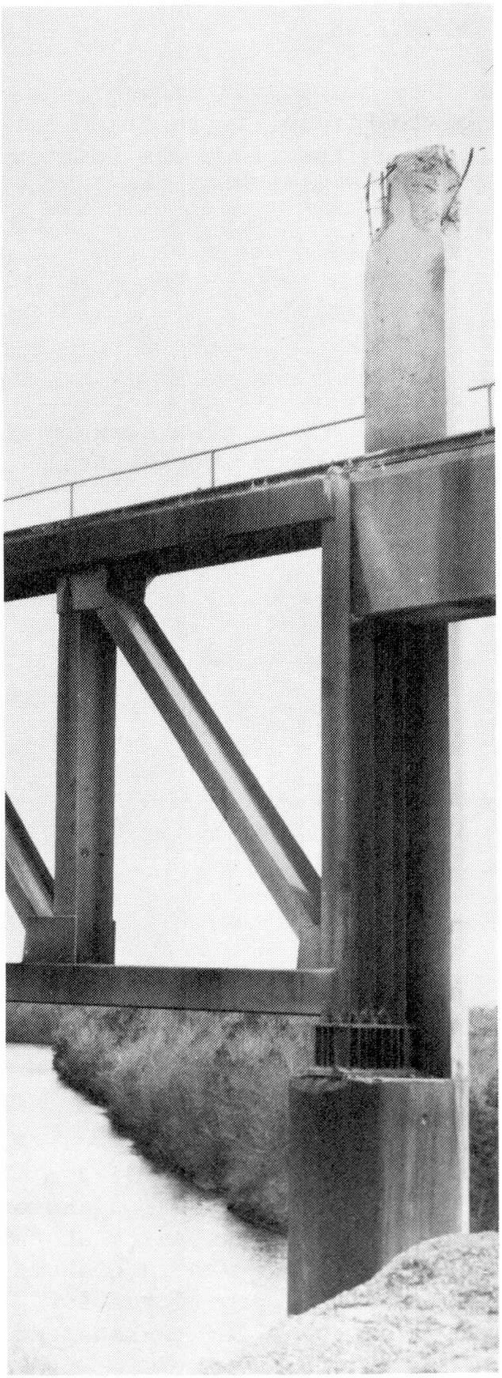


Fig. 2 Weldment of Tensile Reaction

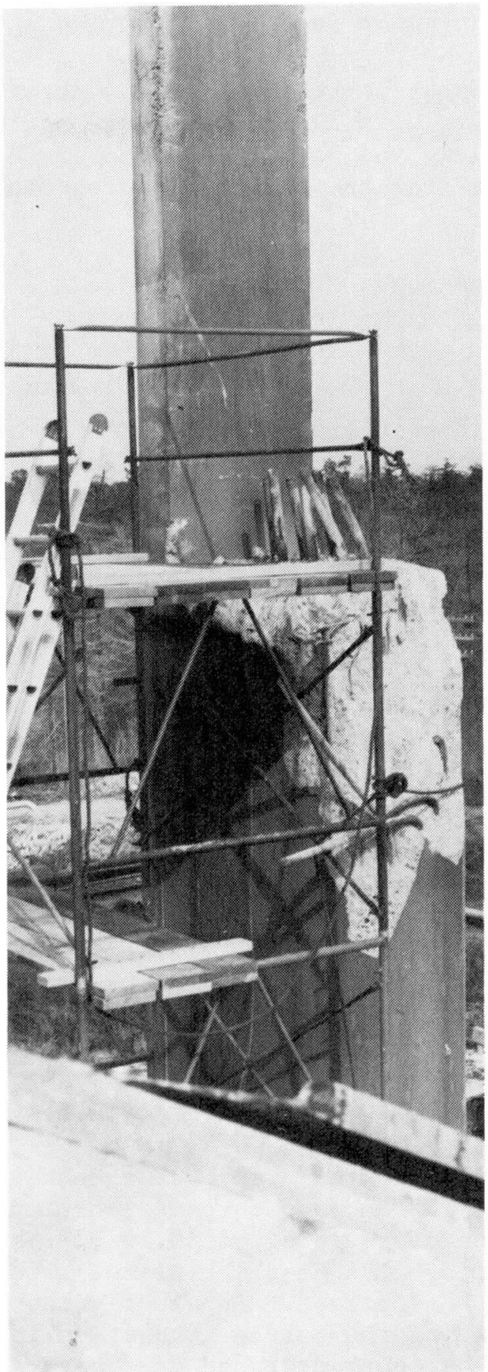


Fig. 3 Failed Anchor Bolts

The tops of five anchor bolts with nuts were eventually recovered. These bolts were fractured near the base of the nuts. It was established that fractures occurred in the threaded portions of all of the bolts.

Discussion with the manager of the plant indicated that the crane generally unloaded one barge of oyster shells each day. Since the crane had an 8 m^3 bucket, and the barge supplied about 2600 m^3 of shells, it was estimated that the crane made approximately 400 daily trips out to the end of the trusses. Furthermore, the crane was generally in use seven days a week, except for three or four times a year when the plant was temporarily shut down. Since the plant had been in operation for three years, it was estimated that the anchor bolts had resisted approximately 370,000 cycles of repeated loading prior to the collapse.

2. REVIEW OF AVAILABLE DRAWINGS AND SPECIFICATIONS

The length of the trusses, as shown in the line drawing in Fig. 4, was 35.9 m. With the crane bridge at the end of the truss, in position for unloading the barge, the load of the crane, P, on the truss was located 15.2 m from the compressive reaction. The load consisted of the following:

Crane bridge	764 kN
Trolley	262 kN
Bucket	44 kN
$8m^3$ of oysters	62 kN

Lateral stability was provided by a welded channel connection between the top chord of the trusses and the concrete columns, and a supplemental truss between the ends of the cantilevers.

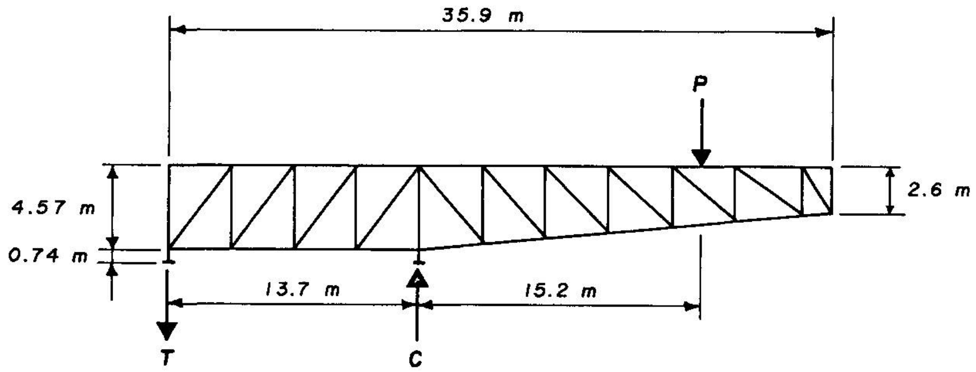
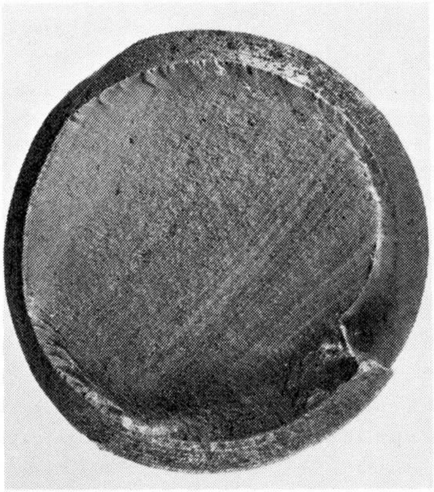


Fig. 4 Elevation of Truss

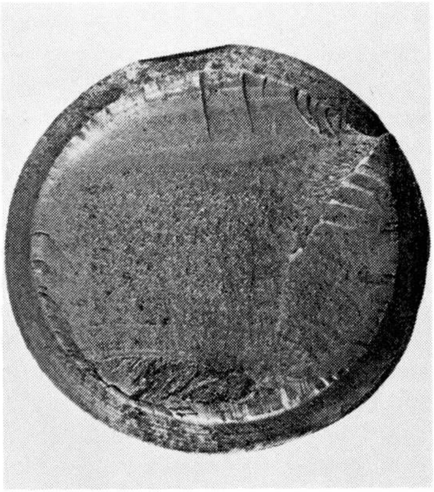
According to the drawings, the anchor bolts had a total length of 3 m with a 152-mm long threaded portion at both ends. The projection above the top of the pier was 0.59 m. The bolts were anchored in pairs at their bottom by a 32-mm-thick plate. The surface of the bolts was in contact with the concrete. Apparently there were no specified procedures for tightening the bolted connection to the truss, although it was reported that the contractor had used a torque wrench.

3. EXAMINATIONS OF THE BOLTS

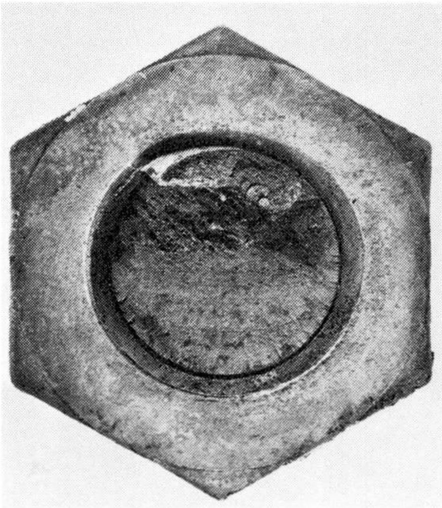
Extensive metallurgical examinations of the bolts were carried out by several parties. There was general agreement that fatigue cracking and fracture had occurred in the threaded portion of all of the bolts. Views of the cracked and fractured surfaces in four of the bolts are shown in Fig. 5. The fatigue cracking appeared to have advanced across the bolts in an intermittent manner. Final ruptures appeared to be due to overloading.



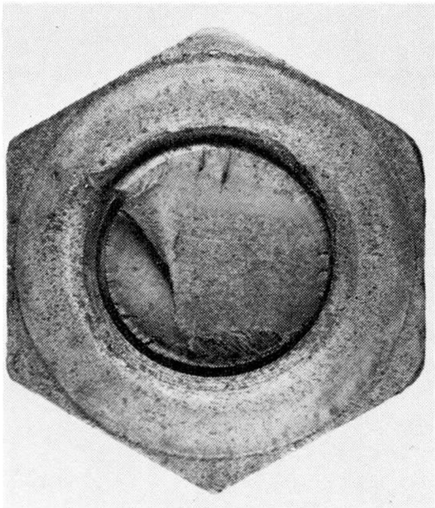
Bolt A



Bolt B



Bolt F



Bolt G

Fig. 5 Fracture Surfaces

A chemical analysis was made on samples obtained from eight bolts. The results were as follows:

	Minimum	Maximum	Average
Carbon	.39	.44	.42
Manganese	.79	.84	.83
Phosphorous	.009	.014	.010
Sulfur	.011	.016	.013
Silicon	.25	.30	.29
Nickel	.10	.19	.12
Chromium	.96	1.03	1.00
Molybdenum	.19	.23	.21
Copper	.04	.14	.11
Aluminum	.01	.04	.03

Physical tests on three samples taken from the bolts indicated that the yield strength, obtained as 0.2 percent offset from the elastic part of the stress-strain relationship, ranged from 268 to 340 MPa, while the tensile strength ranged from 616 to 656 MPa. Charpy V-notch impact test results on three specimens tested at 10 deg C ranged from 33 to 36 Nm.

4. ANALYSIS OF THE CRANE LOADING

The results of an analysis of the compressive, C, and tensile, T, reactions at the points of support of the collapsed truss are presented in Table 1. Three static loading conditions were investigated. It may be seen that the tensile reaction, T, which failed and caused the collapse of the crane varies from approximately 360 kN, when the crane is not on the truss, to 1170 kN when the crane bridge is at the end of the trusses and the trolley is adjacent to the truss. Based on a stress area of 1480 mm^2 through the root of the threads of the anchor bolts, and on the assumption that the load is distributed uniformly to all ten anchor bolts, the preceding values correspond to tensile stresses of 24 and 78 MPa, respectively.

TABLE 1 - STATIC LOAD REACTIONS FOR THE COLLAPSED TRUSS

Load	Compressive reaction (kN)	Tensile reaction (kN)	Nominal stress per bolt at tensile reaction (MPa)
Weight of truss	1125	360	24
Crane bridge at end of truss, trolley in center, and full load of oysters in bucket	2340	990	69
Crane bridge at end of truss, trolley adjacent to truss and full load of oysters in bucket	2700	1170	78

It was estimated that the truss reactions may be magnified approximately 30 percent by dynamic effects. Accordingly, the average tensile reaction that may be imparted to the system of anchor bolts was estimated to be 360 + 1.3 (990 - 360) or approximately 1180 kN. This corresponds to a nominal stress per bolt of 79 MPa.

There may have been further potential for a small amount of magnification of the stresses in the anchor bolts due to lateral forces creating a moment perpendicular to the truss. This moment would be expected to have the greatest effect on the most remote pairs of anchor bolts. However, the primary mechanism for resisting lateral forces was provided by the channel connection welded between the top of the truss and the adjacent higher part of the column.

5. EVALUATION OF FATIGUE STRENGTH

Fatigue test data on threaded parts is limited, at least in North America. However, early tests by Moore and Henwood [1] clearly indicated the importance of stress and the characteristics of the threads. Zero-to-maximum axial tension tests on medium-carbon 9.5 mm studs with die-cut threads had an endurance limit as low as 90 MPa. Low cycle tests on bolts have also been reported by Snow and Langer [2].

More recently (subsequent to the collapse described in this paper) Frank [3] reported on an experimental investigation of anchor bolts that included the following variables: steel type, thread pitch, bolt diameter, method of forming thread, galvanizing and double nuts. Frank concluded that the type of steel, thread size, and bar diameter do not significantly influence the fatigue strength of anchor bolts. The fatigue strength of double-nutted bolts subjected to bending or tension, tightened to one-third of a turn past snug, exceeded the strength of single-nut anchor bolts. According to Frank, the present AASHTO [4] Category E design stress range provides a suitable lower bound design relationship for single-nut anchor bolts and double-nutted anchor bolts tightened to less than one-third of a turn.

The AASHTO Category E design stress range is shown in Fig. 6. Superimposed on the plot is a point representing a nominal stress range of 55 MPa and 370,000 cycles at which the truss is estimated to have collapsed. The failure occurred well below the Category E design range.

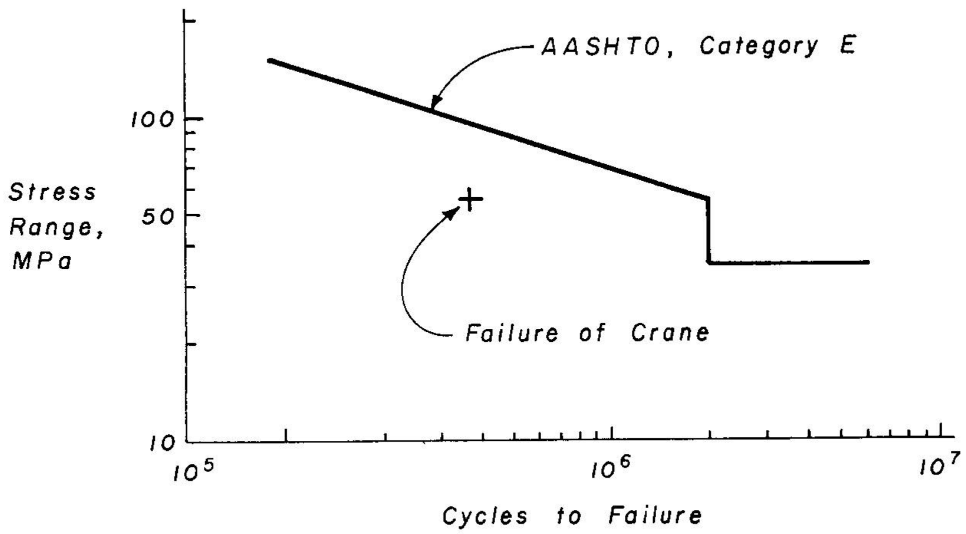


Fig. 6 Comparison of Failure Condition to AASHTO Category E Design Criteria

It should be noted that the AASHTO Category E design stress range is established on the basis that there is a 95 percent level of confidence that 95 percent of the failures will exceed the design condition. There were also a number of uncertainties in the determination of the stress range and cycles causing the failure. However, the most plausible reason for the failure occurring below the Category E design range is lack of uniformity of stress in the anchor bolts. The method of construction apparently did not insure that the stress was uniform when the system was placed in operation. With time, there may have been considerable variation in the bond between the surface of the bolts and the concrete, which may also have had a significant influence on the stress conditions, irrespective of their adequate end anchorage. Consequently, it is likely that stress ranges as high as 150 to 200 MPa may have occurred in some of the bolts. As noted earlier, the examination of the fracture surfaces indicated that the fatigue cracks advanced across the bolts in a variable manner.

6. FINDINGS

The collapse of the crane occurred as a result of fatigue failures of the anchor bolts. Considering the potential for unequal stresses in the bolts, it was not surprising that the number of cycles to failure was less than the fatigue life indicated by tests on single bolts. More importantly, a structural connection should have been used for the tensile reaction which would not have allowed fluctuating tension in the anchor bolts.

REFERENCES

1. Moore, H. F. and Henwood, P.E.: The Strength of Screw Threads Under Repeated Tension, Bulletin 264, Engineering Experiment Station, University of Illinois, March 1931.

2. Snow, A. L, and Langer, B. F.: Low Cycle Fatigue Strength of Large Diameter Bolts, Journal of Engineers for Industry, American Society of Mechanical Engineers, Vol. 89, Series B, No. 1, February 1967.

3. Frank, K. H.: Fatigue Strength of Anchor Bolts, Journal of the Structural Division, American Society of Civil Engineers, Vol. 106 No. ST6, June 1980.

4. American Association of State Highway and Transportation Officials: Standard Specifications for Highway Bridges, Twelfth Edition, Washington, D. C., 1977.