

## DESIGN, MANUFACTURING, TESTING, AND DEPLOYMENT OF A CROSS HAUL BUCKET FOR THE INDEPENDENCE HUB

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### ABSTRACT

This paper provides details on the design, manufacturing, analysis, testing, and deployment of cross-haul buckets used for the pick up, cross haul, and hang off installation of the Independence Hub Steel Catenary Risers in MC 920 in 8000 feet of water depth. The objective in testing was to measure the load capacity of the cross-haul buckets and verify that they were fit for service.

The buckets were tested at Stress Engineering Services, Inc. who designed the set up. The test subjects included 20-inch, 10-inch / 8-inch, cross-haul buckets. Strain gages were applied to the lugs of the samples to measure strain during loading. Loads corresponding to the flooded weight of the SCR with dynamic load factors were applied to the samples 15-degrees from vertical (8-inch bucket) and 22-degrees from vertical (20-inch bucket). A 625 mT (1,378 kips) load was applied to the three 10-inch / 8-inch cross-haul buckets and no significant through-wall yielding of the bucket was observed. For the 20-inch cross-haul bucket, a load of 1064 mT (2,345 kips) was applied and no significant through-wall yielding of the bucket was observed, indicating the buckets were adequately design for their intended service.

### BACKGROUND

Among the major challenges that were encountered during the execution of the Independence Hub project in MC920 in 8,000 ft of water depth was the installation of the steel catenary risers (SCRs) [1] [2]. The availability of suitable installation vessels for the pipelines and SCRs in this deep water has dictated the selection of the installation method and approach. As such the SCRs have been laid on the seabed before the installation of the Independence Hub semi-submersible. This approach made the SCR pick up, cross haul from underneath the semi hull and then hang off a challenge.

The cross haul of the SCRs from underneath the semi has required an installation aid tool that would support the SCRs on the opposite side of their final receptacle locations while allowing for the installation vessel to move around the hull to the other side to complete the installation. The flexjoint receptacles for the initial and future SCRs were used for the temporary support of the SCRs since these receptacles have already designed to support the SCRs during operations.

The installation tools which are called the “cross haul buckets” were designed by Oil States Industries, Inc. (OSI) with input from The Independence Hub Execution Team as well as Heerema, the installation contractor. There were three for the 10-inch and 8-inch production SCR receptacles and one for the 20-inch gas export SCR receptacle. The cross haul buckets were fabricated at the OSI facility in Houma, Louisiana.

In addition, a fit-up test was also conducted at the Kiewit yard in Corpus Christi when the Independence Hub Semi was there for deck integration. This was to provide assurances and to avoid any surprises during the offshore installation. The paper briefly describes the steps of the SCR installation using the cross haul buckets.

### TOOL DESIGN AND ANALYSIS

The design of the cross-haul tools were required to meet the following functional requirements:

- Safely support riser during all transfer and hang-off operations
- Mate with existing socket, spelter, and shackle geometries
- Provide manageable offshore handling, behave predictably and reversibly during insertion and removal from the vessel riser receptacle baskets.

Other design imperatives for the tool were:

- Be constructed of readily available materials
- Critical load design elements that can be inspected effectively using standard visual and non destructive methods
- Employ load connection features familiar to offshore riggers.

Two different tool designs were required due to the different loads and receptacle sizes related to the production and export risers. Design alternatives that were considered included a tool with internal shackle pin, a flexible bearing based design, and a suspended padeye design. Ultimately, a suspended padeye design fabricated using weldable steel plate was selected due to its simplicity and compatibility with all of the functional requirements and design goals.

### Design Process and Basis

The design basis for the tools included loads based on maximum, dynamic flooded riser weight, with vectored loads corresponding to the complete envelope of relative load transfer during installation

operations. The tool was designed against industry structural design code with a minimum safety factor against strength capacity overload of 2 and a factor of 10 against buckling.

The material used for the cross haul buckets was ABS grade EH36 steel plate with minimum specified yield strength of 51 ksi and ultimate tensile strength (UTS) between 70 and 90 ksi. The typical actual yield strength for the plate that was used on the cross haul tool or bucket was 55 ksi and the typical UTS was 75 ksi.

Other design features included pad-eye centers that were offset to cause the tool to hang at a natural angle favorable to insertion into the vessel riser receptacles, which had approximately 10 to 12 degrees tilt from vertical in order that they will be aligned with the neutral departure axis of the permanent steel catenary risers.

One of the keys to the eventual success of the design process was that the client insisted on regular face-to-face and teleconference meetings during the definition of the operational load spectrum, design conception, review of alternatives, analysis review, and manufacturing planning. Also, because this was a previously untried tool concept, the tool supplier assigned two independent stress analysts for the work.

### Analysis Methods

In terms of critical sections, the selected tool design was considered to have three basic functional sections. The first was the lower padeye, which needs to support the complete riser without tear-out or tensile failure. Second, the load ring that provides load transfer to the riser receptacle must be sufficiently stiff to resist buckling or other deformation that would allow pull-through of the pad-eye. Third, the upper padeye must withstand loads associated with the weight of the cross-haul tool itself and any rigging and lines suspended from the tool. Finally, as the padeye and load ring sections of the cross-haul tools were constructed of laminated plates joined by partial penetration welds and a number of steel through-pins, stress analysts were also careful to review stress and deflection components that exploited the planar interfaces between the plates in mode I, II, or III deformation. Solid non-linear finite-element modeling with contact behavior was employed to analyze the stress and deflection behavior in the two cross-haul tool designs. The tear off mode of failure was investigated using linearized stresses from the finite element approach and the results were compared with the allowable stresses based on API RP 2RD [3].

**Figure 1** provides a schematic detailing the general arrangement for the design of the cross haul bucket too, while **Figure 2** shows the von Mises stress distribution based on a finite element analysis for the tool subjected to accidental loading conditions.

### TESTING

Included in the paper are discussions on the test methods, as well as instrumentation that were used to monitor the cross-haul buckets during testing. Results are presented including strain gage results showing stress distributions measured in each of the tools during testing.

#### Testing Methods and Set-up

Tri-axial strain gage rosettes were applied to the lugs of the cross-haul buckets to measure strain during loading. The strain gage locations for the 20-inch bucket and 10-inch/8-inch buckets are shown in **Figure 3** and **Figure 4**, respectively. Load was applied to the bucket by four 2.25 million pound hydraulic cylinders and reacted

through a shaft connected to the lug on the bucket by pins and spacer plates. A diagram of the test set-up is shown in **Figure 5**. A photograph of the 10-inch/8-inch bucket with the reaction shaft is shown in **Figure 6** and the assembly prior to testing is shown in **Figure 7**.

To accommodate the reduced angle of 15-degrees for the 10-inch/8-inch tools, a wedge insert was placed on top of the angle block originally set-up for the 20-inch tool pulled at an angle of 22-degrees. Other than the change in angle and applied load, the testing approach was basically the same for both tool sizes.

The following steps were involved in the testing the Independence cross-haul buckets.

1. Start the data acquisition system to record data. Record data at 1 scan per second.
2. Apply load in the following sequence for the corresponding bucket size (loading rate not to exceed 2,000 lbs. per second):
3. Remove load and stop data acquisition system.

The following sections provide specific details on the magnitude of loads to which the two cross-haul buckets were subjected \*8-inch and 20-inch tools).

#### 10-inch/8-inch SCR Cross-haul Buckets at 625 mT (15 degrees)

Listed below are sequence of loading to which the 10-inch/8-inch tool was subjected.

1. Apply 25% of load and hold for 5 minutes (344,468 lbs).
2. Apply 50% of load and hold for 5 minutes (688,937 lbs).
3. Apply 75% of load and hold for 5 minutes (1,033,406 lbs).
4. Apply 100% of load and hold for 15 minutes (1,377,875 lbs).

#### 20-inch SCR Cross-haul Bucket at 925 mT (22 degrees)

Listed below are sequence of loading to which the 20-inch tool was subjected.

1. Apply 25% load with 1 minute hold (639,334 lbs).
2. Apply 50% load with 1 minute hold (1,278,668 lbs).
3. Apply 75% load with 1 minute hold (1,918,002 lbs).
4. Apply 100% load and hold for 5 minutes (2,038,000lbs).
5. Apply 105% load with 1 minute hold (2,140,000 lbs).
6. Apply 110% load with 1 minute hold (2,242,000 lbs).
7. Apply 115% load with 1 minute hold (2,343,000 lbs).

### TEST RESULTS

The results associated with the test program included the strain gage results and evaluating the overall performance of the tool relative to the imposed loads. Both the 10-inch/8-inch and 20-inch tools performed as intended and no unexpected results occurred. Visual examination after testing revealed that no cracks or plastic deformation had resulted during testing. The sections below provide specific results for each tool that was tested.

#### 10-inch/8-inch Cross-Haul Bucket

Test results are presented for one of the 10-inch/8-inch cross-haul buckets (three different 10/8-inch tools were tested, but results are only presented for the first one tested as it is representative of the performance of the others). From the strain gage results, principal stresses are calculated for strain gages nearest the eye and at the top of the pad-eye. From the principal stresses the von Mises equivalent stress were calculated and the results are plotted in **Figure 8**. These gages were located in areas where high stresses were expected. The highest measured elastic stress was at strain gage #6. This gage was

located two inches from the edge of the eye and 15 deg from the load direction.

**Table 1** presents the calculated von Mises stress results for all three (3) 8-inch tools. As observed, there is minimal difference among the calculated values (mean of 38.5 ksi with a standard deviation of 3.8 percent).

**Table 1 - von Mises stress at 625 mT in 10-inch/8-inch tool**  
(Results measured by Strain Gage #6)

8-inch Cross-haul Bucket #	Maximum Principal Stress (ksi)
1	37.01
2	38.75
3	39.93

### 20-inch Cross-Haul Bucket

Test results are presented for the 20-inch cross-haul buckets as only one of this tool size was tested. The von Mises stresses measured by the strain gages nearest the eye and at the top of the pad-eye are plotted in **Figure 9**. These gages were located in areas where high stresses were expected. The highest measured elastic stress at 925 mT was 52.58 ksi from strain gage #6. This gage was located two inches from the edge of the eye and 22 deg from the direction of loading.

### FIELD INSTALLATION

The SCR pick up, cross haul and hang off installation consists of four main steps; namely, pick up, cross haul, transfer to crane and pull-in [1] [2]. The SCRs are picked up by Heerema's the Balder installation vessel, using the vessel A&R wire. Meanwhile the cross haul wire is connected to two cross haul buckets pre-set at two receptacles on the opposite sides of the semi hull. Once the SCR head and rigging reach a certain depth (e.g. approximately 1,000 ft to 1,500 ft), the Balder crane lifts the cross haul bucket from the receptacle and connects its cross haul wire to the SCR rigging after recovering the cross haul bucket to the Balder deck. Then the Balder recovers the A&R wire and move to the other side of the semi where the SCR is hanged off by the cross haul bucket. The Balder will again deploy its A&R wire and transfer the SCR rigging from the cross haul wire to the A&R wire for recovery to the Balder. **Figure 10** shows a cross haul bucket during installation. The SCR load is then transferred to the Balder's crane for the last step of the SCR installation by pulling in the SCR towards its final receptacle location. **Figure 11** shows the Cross Haul Bucket being retrieved from Receptacle P15 to the Balder Stern Hang-off Platform during the installation of the SCRs.

### CLOSING COMMENTS

This paper has presented information on the design, manufacturing, testing, and deployment of the cross haul bucket tool. The following observations are made in reviewing the Independence Cross-Haul Bucket test results:

- Highest measured strains were located around the eye.
- No significant through-wall yielding was observed in the 8-inch cross-haul buckets.
- No significant through-wall yielding was observed in the 20-inch cross-haul bucket.

The program associated with this study is a good example of how engineering can make use of several disciplines including design, analysis, and testing to develop tool necessary for specific functions. By using engineering-based evaluation methods, the program team was better positioned to ensure the successful deployment of the tool in the field.

### REFERENCES

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- [2] Bouwman, J. et al. "Installation Challenges: Lifting and Pull-in of the 20-inch SCR," Proceedings of the Offshore Technology Conference, OTC 19061, Houston, Texas, 30 April - 3 May 2007.
- [3] API RP 2RD. "Design of Risers for Floating Production Systems (FPSs) and Tension Leg Platforms (TLPs)." First Edition, 1998.
- [4] Kumar, A., "20 inch SCR Installation Cross Haul Temporary Support Tool Finite Element Analysis and Load Capacity Prediction Summary Report", Rev. 0, December 1, 2006.
- [5] American Petroleum Institute, "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms - Load Resistance Factor Design", API RP 2A-LRFD, July 1, 1993.

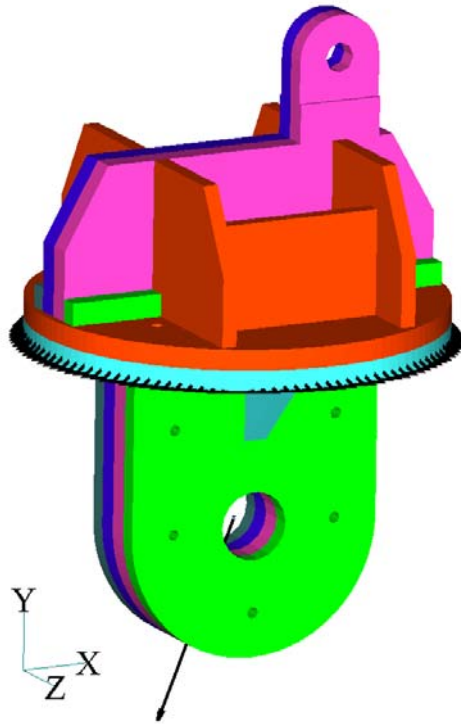


Figure 1 - Fabricated Cross-haul Tool Elements and Load Boundaries

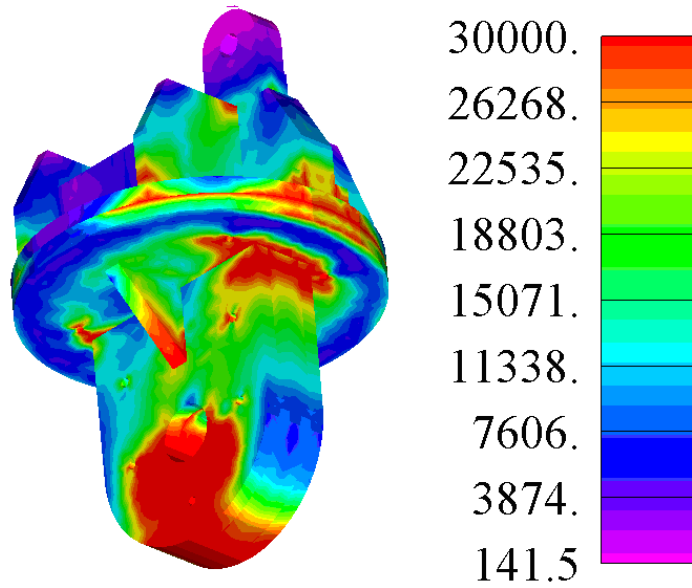


Figure 2 - 20-inch Cross-haul Tool von Mises Stress at Maximum Accidental Load  
(contour plot scale in units of psi)

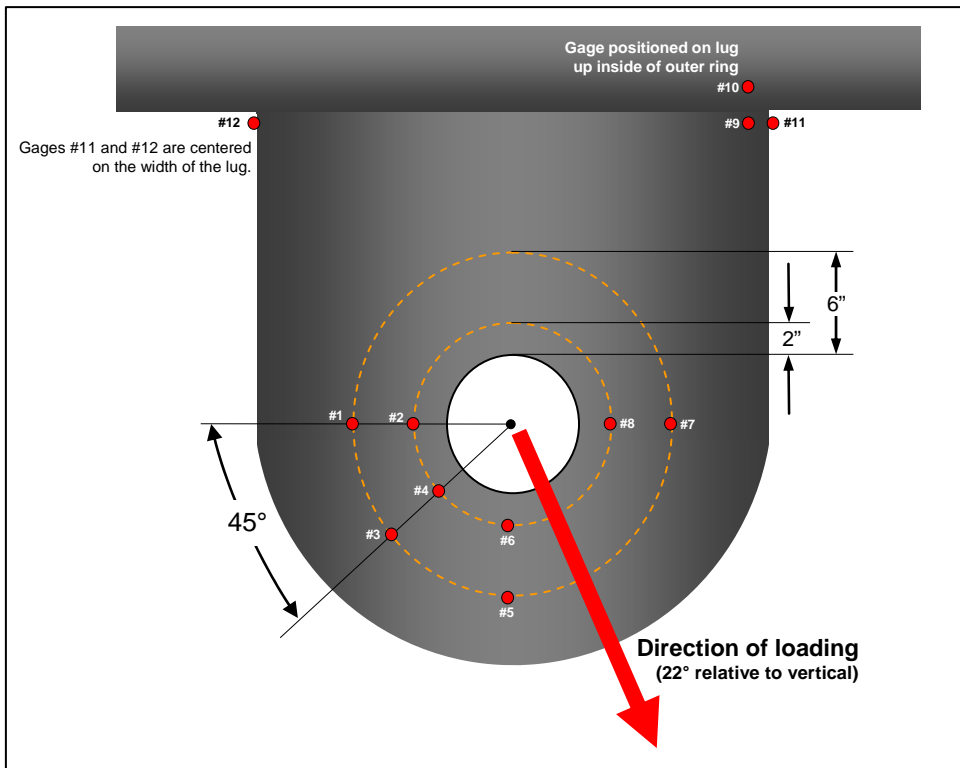


Figure 3 - Diagram of Strain Gage Locations for 20-Inch Cross-Haul Bucket

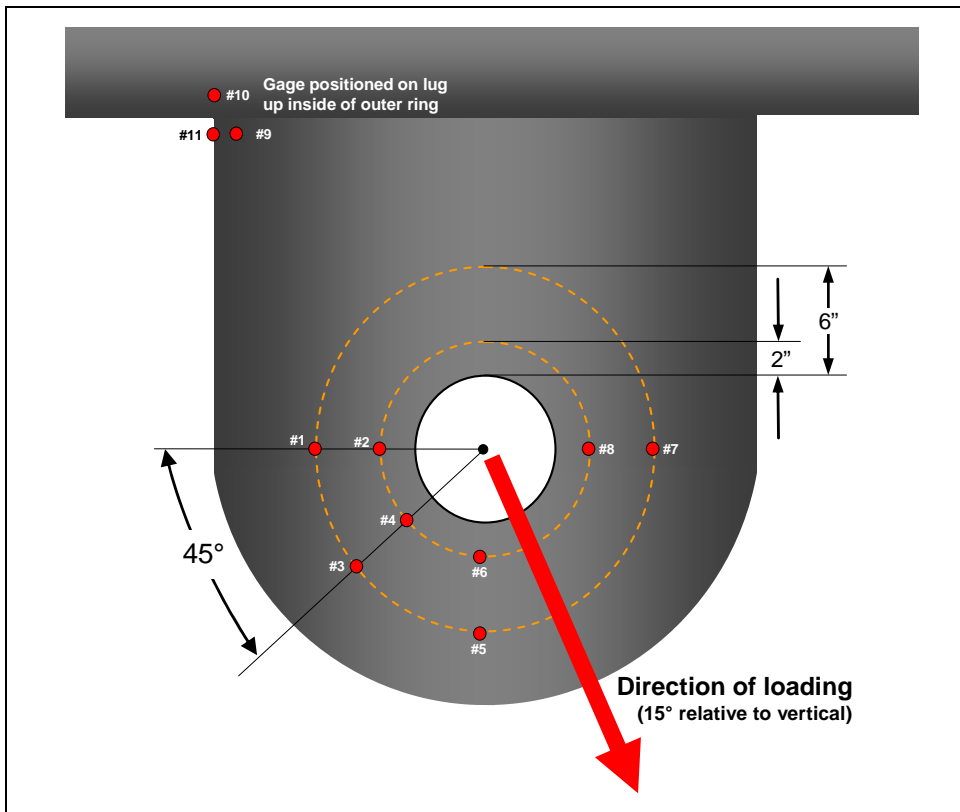
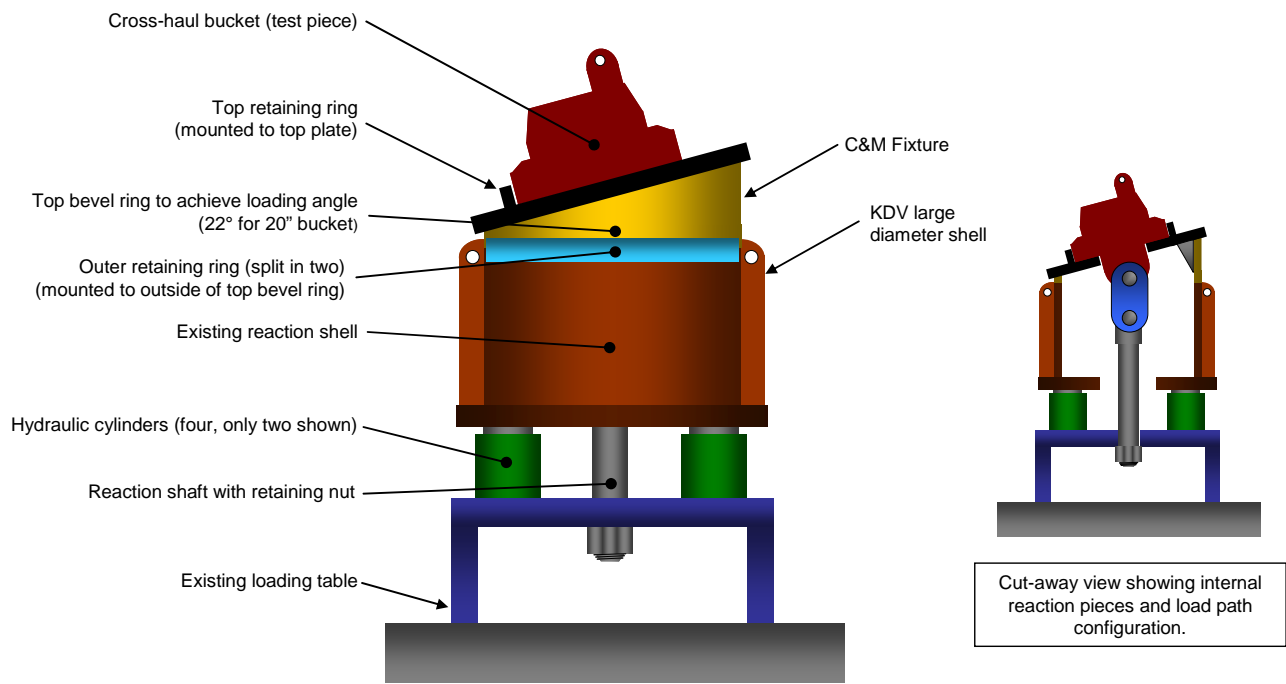


Figure 4 - Diagram of Strain Gage Locations for 10-inch/8-Inch Cross-Haul Bucket



**Figure 5 - Diagram of Cross-Haul Bucket Test Set-Up**



**Figure 6 - Assembled Cross-Haul Bucket and Reaction Shaft**



Figure 7 - Test Set-Up for 10-inch/8-inch Cross-Haul Bucket

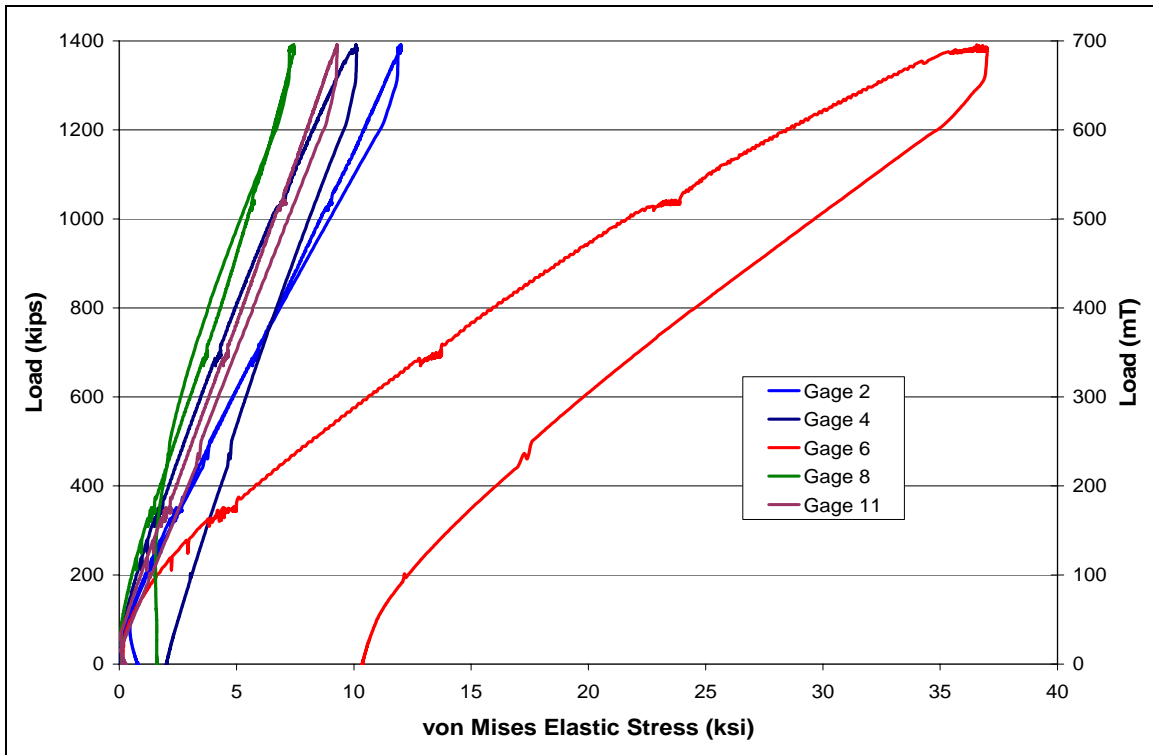


Figure 8 - Load versus von Mises Stress for the 10-inch/8-inch Cross-Haul Bucket #1

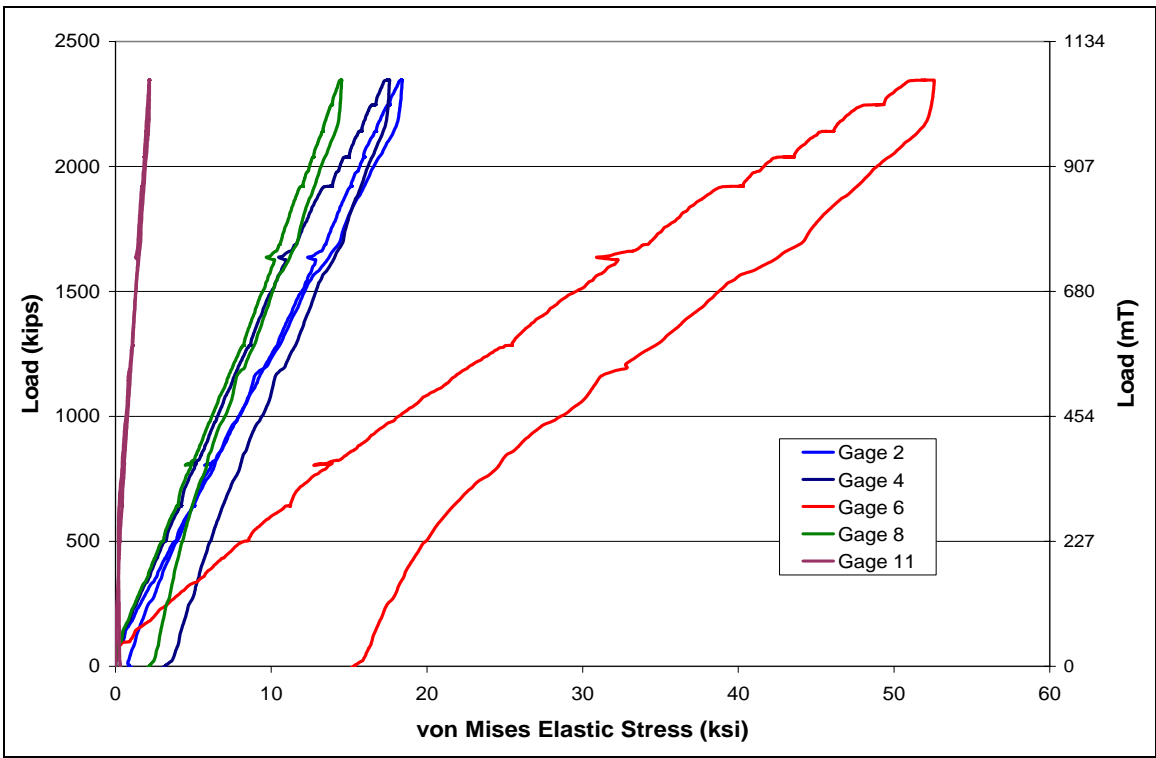


Figure 9 - Load vs. Load Frame Displacement for 20-inch Cross-Haul Bucket



Figure 10 – Cross Haul Bucket during SCR Installation





**Figure 11 – Cross Haul Bucket during retrieval**  
 (Receptacle P15 to the Balder Stern Hang-off Platform)