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STRUCTURAL EVALUATION OF SPENT FUEL TRANSFER WITH A CRANE

**Mike Yaksh, Ph.D., PE
NAC International INC
Norcross GA**

**Suresh Babu, Ph.D.
NAC International INC
Norcross GA**

Abstract

Transfer of spent fuel from the spent fuel pool to concrete casks for long term storage can be accomplished by a variety of designs. In the design under consideration, the fuel is loaded into a welded stainless steel canister in a shielded transfer cask and is then moved to the location having the concrete casks. A gantry crane is used to transfer the shielded transfer cask with the canister from the conveyance to the concrete cask. In this paper, a series of evaluations are presented to confirm the safety of the crane and system. The accelerations from the seismic event are determined from an extensive soil structure evaluation to account for the soil variation as well as the mass distribution due to the partially loaded casks on the pad. Evaluations for the crane use transient analyses in which the results are compared to the allowables defined in the ASME NOG and ASME Section III, Subsection NF Codes. While the peak accelerations are in excess of 0.85g's the actual bounding loading condition was an obligation to factor the vertical accelerations to enforce parity between the vertical and lateral accelerations applied to the base of the crane. To mitigate the member loading due to crane excitation, the design included the use of viscous dampers. The use of viscous dampers was observed to significantly reduce the system response. Sensitivity studies are performed to ensure that the range of crane motion is captured due to tolerances in the viscous dampers. To capture the bounding conditions due to local crane base and pad compliance, additional studies are presented to examine the effect of local pad stiffness. These analyses employ a detailed model of the crane, cabling and transfer cask for all transient evaluations. Results for the crane evaluations confirm that the crane integrity and canister confinement are maintained during design basis seismic conditions.

Introduction

Management of the spent fuel pools at nuclear power plants is important to the continued operation of the power plant. An element of the spent fuel pool management involves storing the spent fuel in a safe condition at a location away from the spent fuel pool. Prior to movement out of the building, the loading of the spent fuel into a canister suitable for long term storage is performed in the spent fuel pool. Once loaded into the canister and the canister is sealed, the manner in which the spent fuel is moved to the concrete pad is site dependent. In the design of interest, the canistered fuel is moved to a designated location at the ISFSI (Independent Spent Fuel Storage Installation) pad in a transfer cask which is then moved to a concrete cask by a gantry crane. The gantry crane is also used to load the canister into the concrete cask. The gantry crane is designed to maintain the load of the loaded transfer cask under the most severe site condition. This paper describes the structural evaluation of the bounding loading condition, which is the Design Basis Accident (DBA) condition.

Description of the System

Preparation of the spent fuel for the long term storage in the concrete cask is initiated by loading the fuel into a stainless steel canister. In the design of interest, which will employ the gantry crane, 87 BWR fuel assemblies are loaded into the canister (weight=103 kips). To maintain the fuel in an inert environment the canister is evacuated, backfilled with helium and the canister is sealed by welding the closure lid to the canister shell. Further details of this design are contained in Reference 1. These operations are performed with the canister positioned in a transfer cask (TFR). The TFR is comprised of steel-lead-NS4FR-steel shells to provide radiation shielding as well as sufficient strength to conduct lifting operations and maintain fuel confinement during the DBA. The weight of an empty TFR is 113.5 kips. Movement of the TFR is performed using two solid trunnions attached to a forging at the top of the TFR. The TFR is maintained in the vertical orientation during all phases of loading, movement and unloading of the canister. The conveyance to the concrete pad is performed using a system very similar to the system described and evaluated in Reference 2. At some sites, the concrete casks are constructed on the pad in their final position on the pad. In this configuration, the loaded TFR is moved from the conveyance to the concrete cask by means of a gantry crane. The crane evaluated in this paper is shown in Figure 1 and the gantry crane weight is 239 kips. The current configuration allows for two rows of concrete casks in the direction of crane motion. The gantry crane design allows for lifting the TFR from near ground elevation (“Down” position of the TFR) and positioning the TFR over either row of concrete casks. In the event of a single centered concrete cask, the crane would be able to move the TFR to the centered position. The crane in Figure 1 is shown in the “Up” position to allow the TFR to be moved over the top of the concrete casks.

Seismic Loading Condition

The peak response spectrum acceleration at the bed rock elevation is 0.4 g’s. The accelerations in three orthogonal directions were determined at the concrete pad surface using a detailed soil structural interaction evaluation for the pad, associated piles supporting the pad, and the concrete casks with the loaded canisters. To account for the uncertainty of the soil properties, separate surface time histories were generated for three soil conditions:

1) BE: soil properties from site bore-hole data (Best Estimate)

2) LB: a lower bound estimate soil properties obtained by factoring BE properties by 0.5
3) UB: an upper bound estimate soil properties obtained by factoring BE properties by 2

It was also determined that the system frequency of the loaded pad could also be altered by more than 10% depending on the number of concrete casks containing loaded canisters. Therefore, three pad configurations were considered:

1) Only a single concrete cask on the pad is loaded with a canister
2) Half of the concrete casks on the pad are loaded with canisters
3) All the concrete casks on the pad are loaded with canisters

This resulted in a 3×3 matrix of the system configurations and a total of nine acceleration time histories at the pad surface were established with the peak ground accelerations (PGA) ranged from 0.46 g's to 0.88 g's. Moreover, the peak acceleration spectral values occurred over an 8 Hz range. For the evaluation of the gantry crane response during seismic conditions, per requirement of the Design Specification, the acceleration time history is factored up so that the PGA is 0.78g's for the acceleration time history with a PGA less than 0.78g's. Instead of evaluating the crane response for all nine time histories, the bounding acceleration time histories are used for the evaluation.

Structural Criteria

Two possible stress criteria's are available to evaluate the crane for the DBA condition.

1) ASME Section III Subsection NF (Reference 3) which is considered to be consistent with the requirements in Reference 1 for TFR handling outside the spent fuel pool location.
2) ASME NOG-1-2010 (Reference 4), which has a detailed criteria of all aspects of a gantry crane.

In the analysis described in this paper, ASME NOG-1is used as the design criteria. In addition to ASME NOG-1 having more comprehensive criteria, using NOG-1 would require lower stresses in the structure to meet the allowables as shown in the Table below for certain stresses (as compared to using Subsection NF). The complete stress criteria is significantly more extensive than shown below. This would, in effect, increase the overall margin of safety of the structure against failure. In the table below, Sy and Su refer to material yield strength and material ultimate strength, respectively.

Stress Type	**ASME Section III Subsection NF (Level D Condition) Stress Allowable**	**ASME NOG-1 (Extreme Environmental) Stress Allowable**
Tension	Su (elastic evaluation)	0.9Sy
Pure Shear	0.42Su	0.5Sy
Combined Shear and Bending	Su (elastic evaluation)	0.6Sy

For certain materials, the difference between the two criteria's could be significant. Member sizes were increased to meet the ASME NOG-1 stress criteria. The secondary benefit was the increased fundamental modal frequencies, which would also tend to reduce the dynamic response by effectively placing the fundamental modes outside the peak spectral accelerations. While the evaluations used time histories, the use of the modal frequencies assisted in understanding the dynamic response.

Gantry Crane Finite Element Model and Conditions

As shown in Figure 2, the finite element model used in this evaluation consisted primarily of beam elements. By using ASME NOG-1, the analysis was essentially restricted to using linear elastic materials for the beam elements. This avoids inputting complex patterns of integration point data for the beam elements.

To prevent excessive motion of the TFR during the DBA, a circular ring located near the axial midpoint of the TFR, identified as the "Restraining Ring", is connected by cables attached to the gantry crane frame. The Restraining Ring is comprised of shell elements. The cables attaching the Restraining Ring to the frame are comprised of cable elements which support tension load only. Solutions showed that a significant portion of the cable loading was due to the "whip" type behavior of the cable due to the initial slack in the cable. Even with the cable restraint, the severe accelerations resulted in some finite rotations in the model. To capture the potential behavior of the finite rotations in conjunction with the continual impact of the TFR with different point of contact with the Restraining Ring, LS-DYNA (Reference 5) was used to determine the dynamic response of the gantry crane.

The model also contains a section of the concrete pad, which served as the means to apply the acceleration time histories from the soil structure interaction evaluation (in three orthogonal directions). As seen in Figure 1, the interface between the gantry crane vertical members and the concrete pad is the Crane Base, which is a structure with significant stiffness. The evaluation of the stresses in the Crane Base was accomplished with a separate model using the results of the dynamic response of the gantry crane. The Crane Base allows the gantry crane to maintain contact with an embedded rail system in the concrete pad. To ensure that a bounding dynamic response was obtained, two conditions are evaluated for the gantry crane vertical members attached to the pad.

1) Simply connected (only translational displacement is constrained. Relative rotation between the gantry crane vertical members is permitted)
2) Translational and Rotational constraint between the pad the gantry crane vertical members.

These two conditions would bound the maximum and minimum rotational stiffness of the pad with the gantry crane base. It would also serve to produce bounding loads for the evaluation of the component responsible for maintaining contact with the embedded rail.

It was observed in the initial evaluations, that the loads in the short sway bars were excessive. ASME NOG-1 restricts the level of structural damping due to the absence of any mechanism to absorb energy in the gantry crane. To improve the gantry crane damped response, an additional structural component was integrated into the design; a viscous damper in series with the short sway bars. The viscous damper is unlike other structural members due to the tolerance of the viscous coefficient which can vary by ±15%. This required additional computer solutions to ensure that the bounding loads are identified in the crane response. While the use of damper elements is common place in standard implicit computer codes, it is not commonly used in explicit codes, such as LS-DYNA. To ensure an accurate solution, a separate verification effort was performed comprised of a single degree of freedom damper using damper values and mass values expected in the gantry crane model. A sinusoidal force was applied to the damper. The model results were compared to a closed form solution and found to be acceptable.

By using bounding acceleration time histories, the number of solutions was reduced to 16 separate evaluations. This included:

1) Two cases for the maximum and minimum values for the damper coefficients
2) Two cases for the restraint at the crane base
3) Four cases for the crane positions
    a. Crane in the “Up” position, trolley positioned minimum distance from end (as observed in Figure 1)
    b. Crane in the “Up” position, trolley positioned at the midspan distance in the transverse direction
    c. Crane in the “Down” position, trolley positioned minimum distance from end
    d. Crane in the “Down” position, trolley positioned at the midspan distance in the transverse direction

Results of the Dynamic Evaluations

The most significant contributor to the development of the forces in the gantry crane is the dynamic response of the loaded TFR. A typical acceleration time history for the TFR is shown in Figure 3. The peak acceleration is approximately 2g’s which would account for the loads in the sway bars which maintain the stability to the gantry crane. With respect to the canister confinement boundary, the bounding condition for the canister lateral loading evaluated in Reference 1 is in excess of 25g’s which is an order of magnitude larger than the accelerations due to the DBA for the transfer condition evaluated in this paper.

As a result of the continual impact of the TFR with the Restraining Ring, the forces in the sway bars reflect the impulsive nature of the TFR impacts. A typical force time history for the sway bar force is shown in Figure 4. While some structural criteria give some additional allowance for the dynamic response, ASME NOG-1 does not.

Using the maximum tensile forces from the results and applying the stress criteria in ASME NOG-1,which requires the evaluation of specific interaction equations, the bounding tensile interaction ratio result is 0.88 < 1.

Conclusion

This paper describes the structural evaluation a gantry crane with a loaded transfer cask containing a canister with spent nuclear fuel for seismic conditions. The analysis results confirm that the gantry crane is structurally adequate during the Design Basis seismic condition and meet the criteria per ASME NOG-1.

References

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4) "ASME NOG-1-2010 – Rules for Construction of Overhead and Gantry Cranes (Top Running Bridge, Multiple Girder), New York, 2010 Edition.
5) LS-DYNA Rev. 971, LSTC Lawrence Livermore, CA, USA

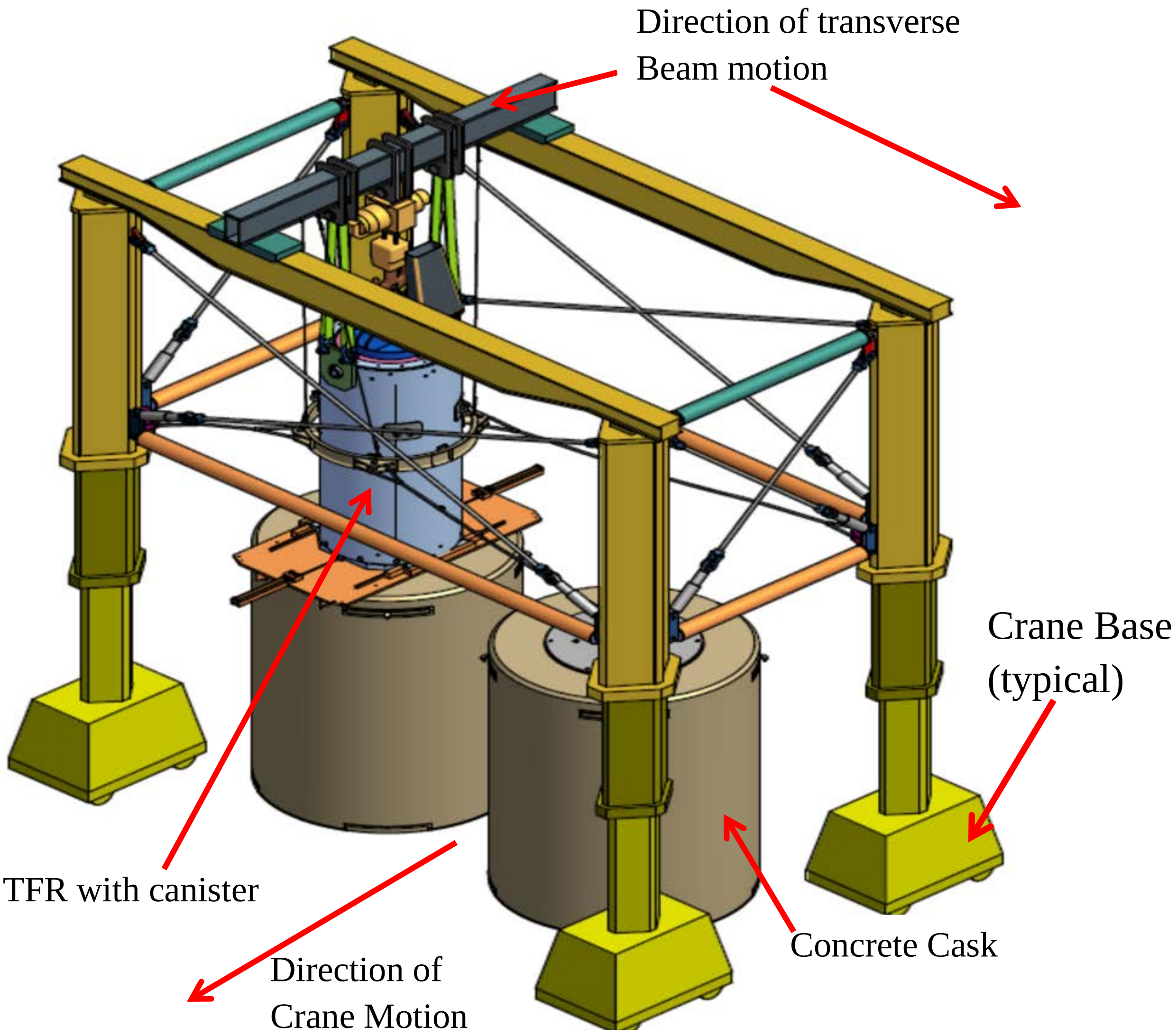

Figure 1 Overall View of the Gantry Crane to Move the Loaded TFR to the Concrete Cask

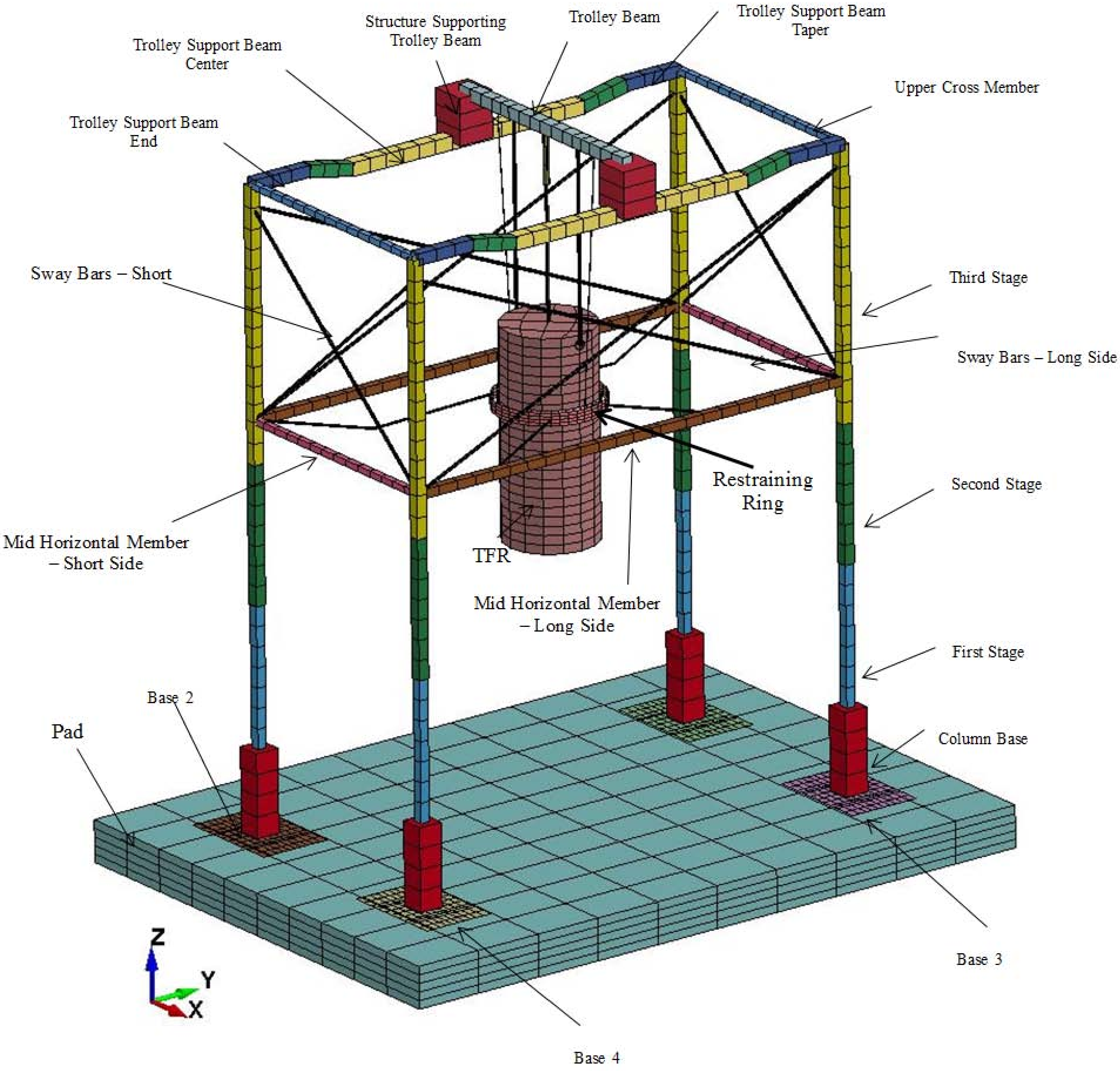

Figure 2 Overall View of the Gantry Crane Finite Element Model

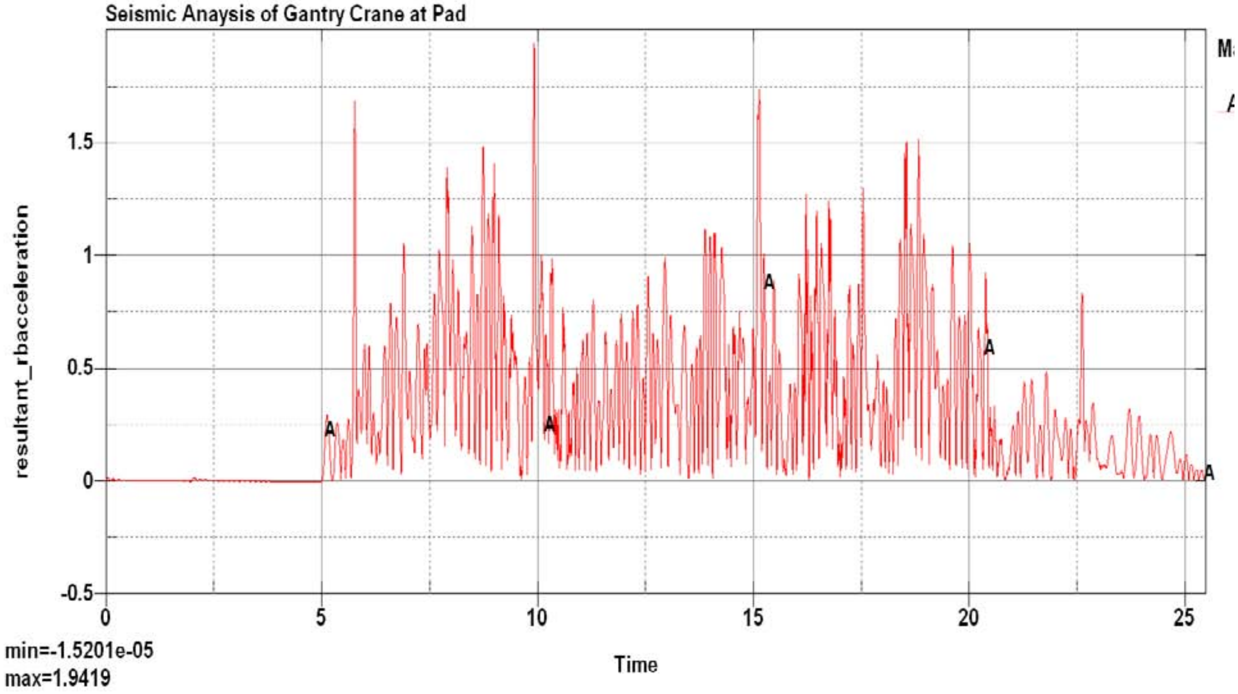

Figure 3. Typical Acceleration (g) Time History (seconds) of the TFR

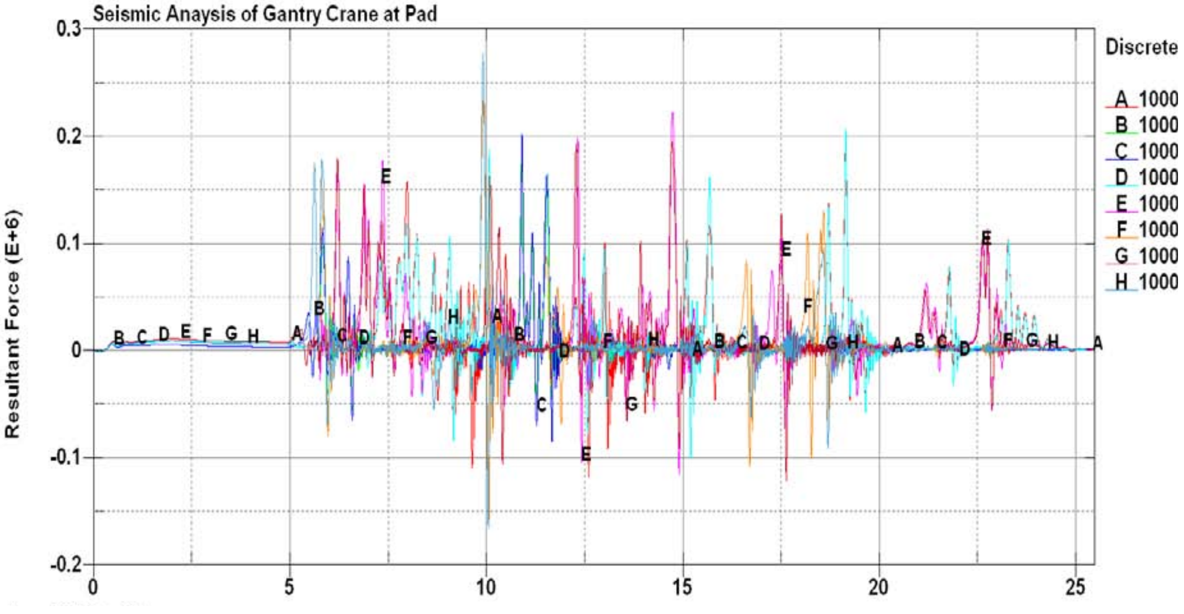

Figure 4. Typical Force (lb.) in the Short Sway Bar versus Time (seconds)