Evaluation of the Dropping of a Propeller Shaft During Installation on the USS COLE a DDG 51 Class Destroyer

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During the installation of a 80,000 pound section of the propeller shaft on the USS COLE, a US Navy Arlie Burk class guided missile destroyer (DDG), a chain hoist failed allowing one end of the shaft to drop about twelve inches onto a bulkhead. If the shaft had been plastically deformed on any part of the shaft it would have to be replaced. This delay would set back the rebuild schedule by six months. A simulation of the shaft and a section of the bulkhead were run to determine whether any damage had occurred. Eight days after the incident it was shown through the use of the LS-DYNA code that the high strength steel shaft was not damaged during the incident. The simulation also illustrated that the area right behind the point of impact on the bulkhead would need to be replaced as this metal was highly strained. As a result of this work and the work of many others in the Navy, Naval Reserve, and Ingles Shipbuilding, the USS COLE has gone into the water ahead of schedule.

The USS COLE arriving in Pascagoula, MS to be repaired. (Courtesy of Ingalls Shipbuilding)
Figure 1

Introduction

A terrorist bomb damaged the USS COLE by putting a hole in the side of the ship that was over 30 feet in diameter and flooded the forward engine room. After the ship was stabilized it was placed on the heavy lift ship, the BLUE MARLIN. The BLUE MARLIN brought the USS COLE back to Ingalls shipyard in Pascagoula, Mississippi for repair as seen in figure 1. The Navy wanted to expedite the repairs to the USS COLE and so parts from the battle damage spare inventory were used to obtain components that needed to be replaced to significantly reduce the lead-time needed.

During the repair it was determined the shafts needed replacement. To do this each section of the shaft is slowly slid into the hull of the ship using rigging to swing it through the openings in the bulkheads. It was during one of these rigging moves that a section of the shaft was being temporarily suspended by rigging during installation into the ship just short of a bulkhead shaft clearance opening. While in this configuration the rigging at the inboard end of the shaft failed. This dropped the shaft about 12 inches onto a temporary channel that was welded to the bulkhead to support the shaft while it is passed through the bulkhead opening.

Background

As it was noted above the shaft sections being installed were the battle spares. If they were damaged for any reason it would take six to twelve months to get a new set fabricated. This would cause a delay, even getting a new set from a DDG under construction would have delayed the progress of the repair by months since the damaged section would have to be removed and the new section inserted.

During installation the shaft was supported about twelve inches from each end as the shaft is moved through the bulkhead openings to its position inside the hull. Since the section in question was the first section in, it had to travel almost two hundred feet into the hull to get into position next to the gas turbine and thrust bearing. It was at this point that the rigging at the inboard end failed dropping the shaft onto the temporary brace that had been welded to the bulkhead in preparation to passing the shaft onto a C channel that was temporarily welded to the vertical bulkhead. This C channel is used to support the shaft while being passed through openings in the inner bulkheads.

The event occurred on Sunday, July 22, 2001. The following Monday through Friday observations and repairs to the bulkhead were made. The only way to do a non-destructive test of the shaft would require mounting the shaft and turning it with strain gages to get final confirmation. This would take a month to setup and another month to undo it if it turned out that the shaft was in fact damaged. To determine what the impact to the installation schedule would be, a full nonlinear material impact analysis of the event was performed using the LS-DYNA software to determine if any damage occurred to the shaft section. This was done that following weekend in the interest of time. Eight days after the event occurred, initial results were electronically submitted back to LCDR Hughes at SUPSHIP Pascagoula the US Naval officer in charge of the repair program. A FEA model used by the shipyard to analyze the shaft indicated that the shaft may have experienced some amount of plasticity. However, there were several model simplifications that raised doubts about the validity of the results.

Onsite Observations

After the incident, observations were made of the damages to the all of the components. The C channel that was temporarily welded to the bulkhead was permanently deformed three inches. In addition, a piece of two-inch angle welded perpendicular to the bulkhead was also flattened against the bulkhead by the shaft. Visual inspections of the shaft indicated that it was OK. However, the inspection was limited due to the fact that the shaft was already inside the ship.

Model

The finite element analysis model of the shaft was built to the minimum of the allowable tolerances specified on the fabrication drawings. To simplify the model the holes in the flange of the shaft section used to connect it to the next section were neglected. This simplification was used to speed up the evaluations since previous experience indicated that the neglecting of the holes would not affect the determination of the presence of plastic strains in the shaft. In addition, the vertical bulkhead is rigidly tied to ground once it is five feet from the point of impact. This was an initial estimate of the distance to conservatively determine the effects of the impact.

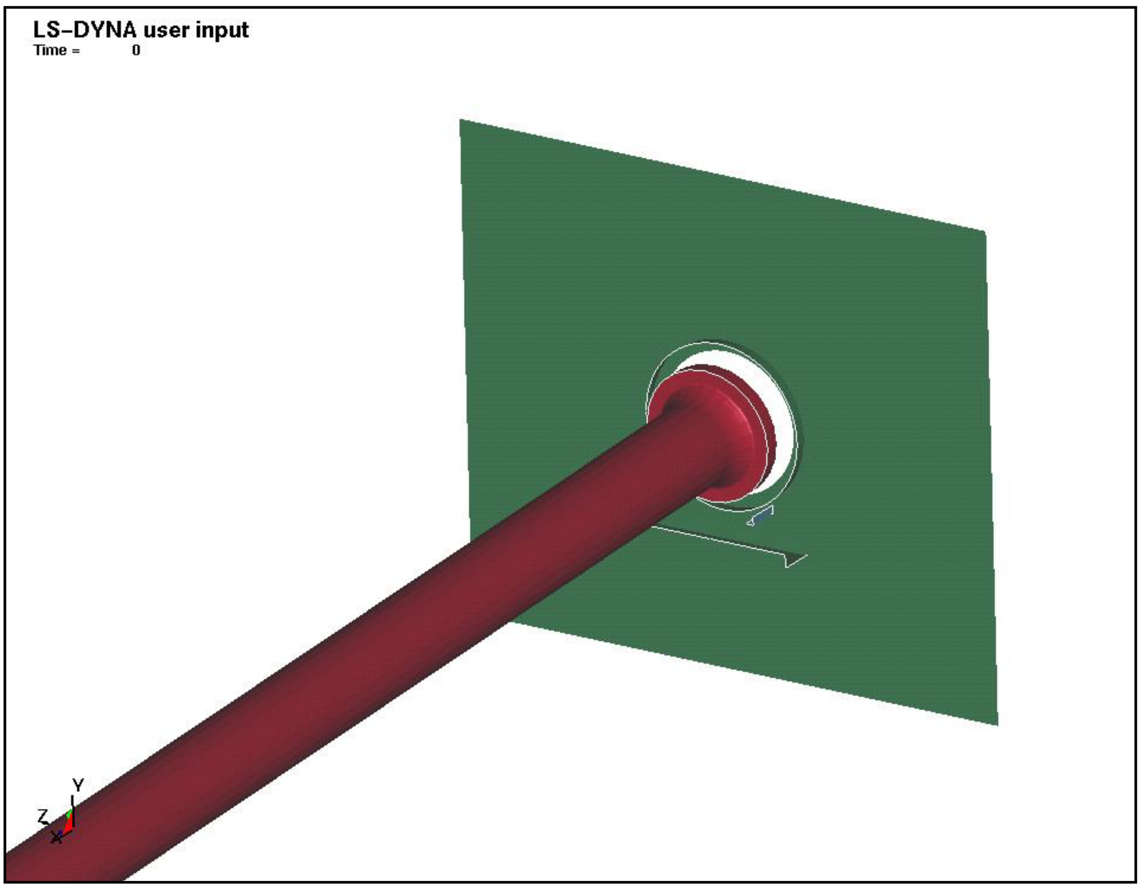
The mesh of the model was created directly from onsite information and fabrications drawings in the ANSYS/LS-DYNA Prep Post product from ANSYS Inc. This mesh was then exported to a standard input file format for LS-DYNA. This input file was then modified to add the parts of the simulation input data that is not supported from within the ANSYS/LS-DYNA Prep Post product. The model as created is illustrated in figure 2.

Material Models

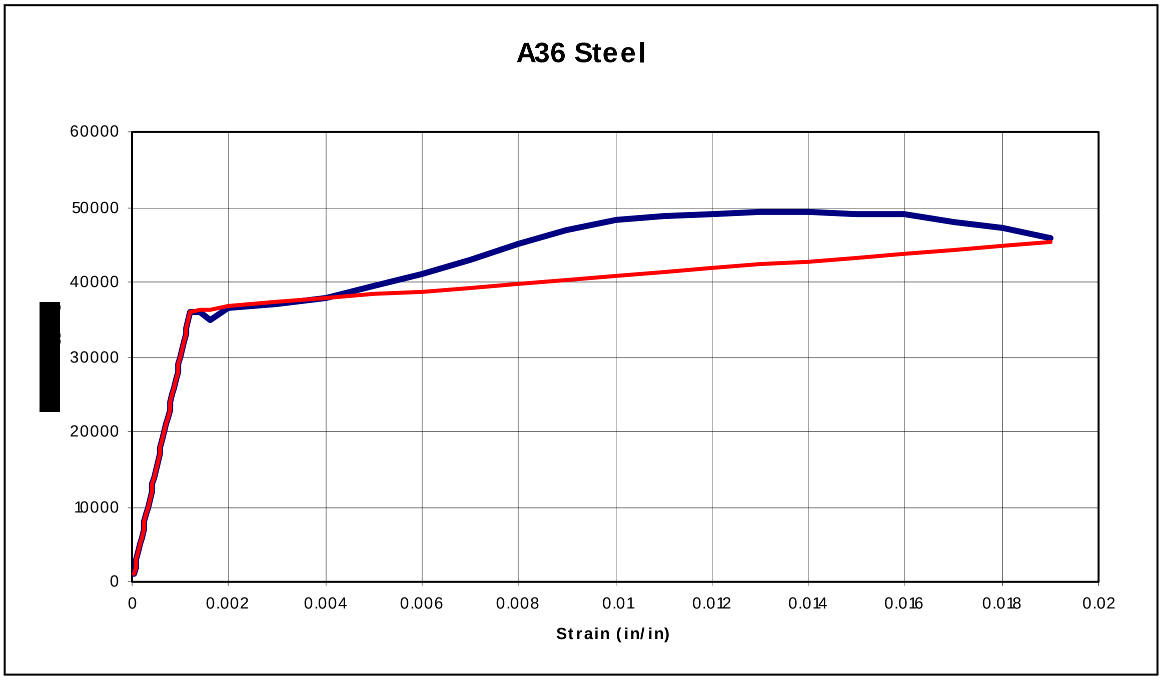
Due to the very short turn around times needed for this project the material property data illustrated in Table 1 was obtained from a web based material property database. There was not time to validate these numbers. As such these values are in question but where used based on the fact that they appeared to agree with data available from the MIL-HDBK-1.

In addition, in order to determine if permanent damage was done to the shaft section a bi-linear post yield material model used in LS-DYNA model as illustrated in figure 3. In addition the standard kinematics Hardening law was used to determine residual strains that would be left if the metal went plastic. It is noted that this law was used since any plastic strains in the shaft would be cause for failure of the shaft section that would require it’s replacement. And therefore the failure criteria is any plastic strains in the shaft section would indicate that the shaft section was not acceptable for use in the USS COLE. In addition, since the bulkhead could be replaced/repaired plastic deformation was accepted. Any areas that were identified as damaged would be heat straightened after the temporary brackets were removed.

Table 1: Material Properties Used To Evaluate	
A36 Steel	
Young's Modulus	28.5e6 psi
Poisson's Ratio	0.3
Tangent Modulus	1e6 psi
Yield Strength	36,000 psi
A36 Steel	
Young's Modulus	28.5e6 psi
Poisson's Ratio	0.3
Tangent Modulus	1e6 psi
Yield Strength	120,000 psi



Model of the shaft section that was dropped and the bulkhead it landed on.
Figure 2



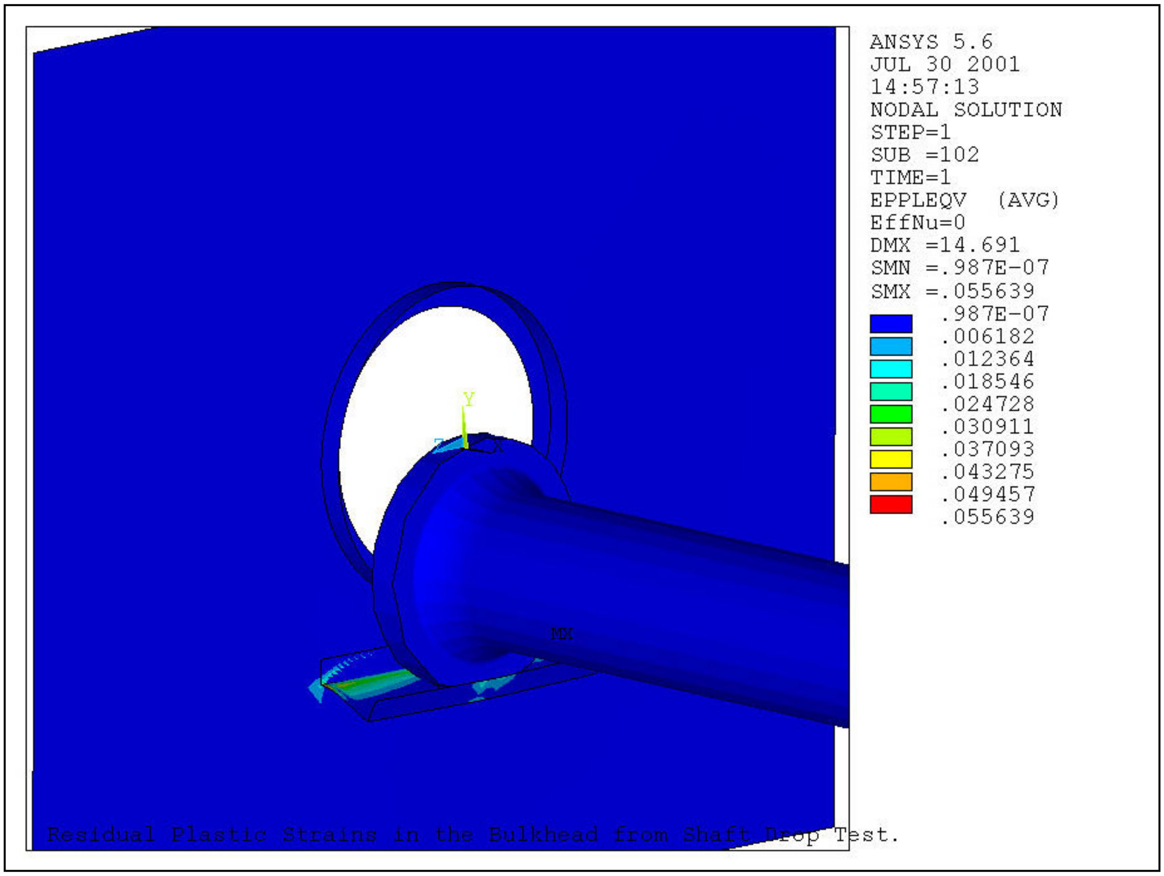
Graph of A36 Steel Material Data and the Bi-Linear Model being used.
Figure 3.

Results of LS-DYNA model

The Model of the shaft drop illustrated that the shaft was not damaged in the incident. The bulkhead and C channel that the shaft landed on absorbed the energy of the impact. In fact the C channel was deformed 3.1 inches in the simulation while the on site observations showed a 3-inch deformation. This basic observation provided the basic validation of the model to the Naval personnel that it was safe to install the shaft and test it 30 days later after the shaft was fully installed and could be NDT while being turned to provide the final proof that the shaft was safe for use at maximum load conditions. The results of the model are illustrated in figure 4.

The Effect on the USS COLE Repair

Since the only significant damage was to some temporary brackets that could be easily replaced the repair schedule was maintained per the Chief of Naval Operations directions. Since this work was done the USS COLE was put back into the water a day ahead of schedule on September 14, 2001 as illustrated in figure 5. After being put back into the water the USS COLE has had all her weapons system and other systems reinstalled. The USS COLE sailed out of Pascagoula, MS on April 20, 2002 to rejoin United States Naval Ships participating in the War on Terrorism. It is hoped that after the events of September 11, 2001 that people in the United States of America never forget about the 19 men and women who died and the heroes who risked their own lives to rescue the injured.



Plastic Strains illustrate that the bulkhead was damaged but the shaft section was not damaged from the being dropped.
Figure 4.

The USS COLE being relaunched in preparation for final outfitting.
(Courtesy of Ingalls Shipbuilding)
Figure 5.