RESPONSE ANALYSIS OF AN AUTOMOBILE SHIPPING CONTAINER

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INTRODUCTION

Rail shipment of automobiles on open rack cars has been plagued with heavy damage claims. To alleviate this problem, systems are needed to enclose the automobile more fully during transit and to mechanize the loading and unloading operations. The Stac-Pac system was developed to meet this need by Southern Pacific Transportation Company.

The system consists of flatcars, Stac-Pac containers, and special loading and unloading equipment. Each 27.2-m (89 1/3 ft) piggyback-type flatcar carries four containers. Three full-size automobiles are carried in each container. The containers are loaded close together on the flatcar so that the automobiles are fully protected during shipment from manufacturer to distribution terminal.

Pullman-Standard developed a container design for the Stac-Pac system and conducted vibration tests to verify the system structural integrity. A dynamic analysis was also made, using NASTRAN, and the results of the test and analysis are compared in this paper.

AUTOMOBILE SHIPPING CONTAINER

The Stac-Pac container built by Pullman-Standard is made of hot-rolled steel (fig. 1). The enclosure of the container is made of thin steel sheet. It serves the dual purpose of protecting the automobile and functioning as shear panels for the structure. The side posts, deck system, and automobile restraining mechanism are made of steel sheets and formed structural shapes. All the substructures are welded assemblies. The container structure is then assembled from these substructures with friction-type bolts. This production method has made the container structure to be effective against dynamic loads.

The outside dimensions of the container are approximately 2.4 m (8 ft) in width, 4.6 m (15 ft) in height, and 6.1 m (20 ft) in length. This size will fit the flatcar construction and satisfy the rail transport regulations. Within this allowable space, the container has to be designed to carry three full-size sedans. It is interesting to note that the tight spatial requirement has made the designing task very challenging.

Recent shipments of automobiles in this type of container has reduced the damage rate to a negligible level. Eventually, the fleet of flatcars and containers will probably extend the automaker's production line to the dealer's show room. In view of the large production potential and the length of service

life, it is very desirable to optimize the container to minimize the cost of
construction and maintenance. Pullman-Standard has carried out extensive de-
signing and testing programs and has chosen NASTRAN as the analytical tool to
achieve this optimization. The analytical and experimental results and the
correlation are reported herein.

VIBRATIONAL TEST

The vibrational test was carried out for the purposes of determining the
response of the structure under simulated rail transport environment and evalu-
ating the fatigue life.

A 27.2-m-long (89 1/3 ft) flatcar normally used for carrying Stac-Pac con-
tainers was the test bed. The container was mounted at one end of the flatcar.
The end position containers are usually subjected to maximum road excitation.
A variable-speed shaker consisting of two eccentrically mounted rotating disks
was located approximately 0.6 m (2 ft) from the open end of the container with
the axes of rotation parallel to the long axis of the flatcar. In this parti-
cular test, the initial position and phase lag of the disks were arranged so
that the maximum vertical and horizontal excitation would occur in phase.

For the purpose of monitoring test data, a number of strain gages and
accelerometers were mounted on the container at key locations. During the test,
the time histories of these strains and accelerations were directly recorded on
photosensitive paper.

Vibration amplitudes and test frequencies were based on road test data.
In this test, two frequencies of 5.0 and 6.25 Hz were used (1 Hz = 1 cps). The
maximum acceleration at the base of the front post of the container is approxi-
mately 0.4g and 0.7g for the 5.0-Hz and 6.25-Hz excitation, respectively. The
fatigue test was performed with 50 hours of continuous excitation at 6.25 Hz.
During this period of 50 hours, the structure of the container would encounter
about 1 million cycles of stress reversal at the amplitude level indicated by
the aforementioned 0.7g acceleration. There was no failure of structural mem-
bers or connections at the end of the test. The accelerations and strains re-
corded show good correlation with the theoretical results computed by NASTRAN.
Representative sets of data are presented in figure 2.

THEORETICAL ANALYSIS

NASTRAN Rigid Format 8, Direct Frequency Response, was used for theoretical
analysis. The first part of the analysis was done on the container structure
alone with a 32 grid point model. This small model served as a pilot analysis
for the purposes of studying the general dynamic behavior of the container and
verifying the proper running of NASTRAN on a CDC 6400 computer under Operating
System Scope 3.4.

The final response analysis was performed with a model which included the
shaker, container, and flatcar. The model had 145 grid points and 300 CBAR and

67 CSHEAR elements. Two major assumptions were made in the process of formulating the model. First, the formed structural shapes were assumed to be capable of resisting all the moment and force components. Second, the thin steel sheets were assumed to be functioning as shear panels only. The correlation between the theoretical and experimental accelerations shown in figure 2 indicates that the assumptions were correct.

The theoretical model is supported by two hinges at the center plates of the flatcar. Therefore, free-free rotational vibration is allowed about the axis passing through these two hinges. The COUPMASS feature in NASTRAN was used to obtain an even mass distribution of the model. The centrifugal forces generated by the rotation of the disks of the shaker were used as the input excitation. The responses of the container were computed by NASTRAN in terms of grid point displacements and accelerations as well as forces and stresses in the structural elements. The output of the program gives the response quantities in the form of magnitude and phase angle. Both the print and punch options were requested in the output. The card images of punch file are stored on magnetic tapes. These data will be reprocessed by an in-house program to compute the responses of the container at 36 time intervals in the excitation cycle. The instantaneous structural deformations at each interval will be plotted to serve as visual aids. Both the 5.0-Hz and 6.25-Hz responses were computed. The calculated accelerations are shown in figure 2.

CONCLUDING REMARKS

The analytical results from NASTRAN have correlated well with the experimental data. NASTRAN has proved to be a powerful tool in this application of analyzing railroad transportation equipment. In particular, NASTRAN can be used to optimize many design parameters with a reasonable amount of time and expenditure and to minimize repetitious testing procedures and prototype improvement in further refinement of the container design.

In the railroad industry, a trial-and-error approach using static analysis and testing has been the general practice. Dynamic analysis has not been applied in designing railroad equipment except in a few cases. The dynamic analysis reported herein indicates that a substantial saving in cost and time can be realized in new product development compared with the conventional approach.

The COUPMASS feature in NASTRAN helps to distribute the masses of the container more evenly with a relatively small number of grid points available in the theoretical model. It is a very useful option.

The direct solution technique that computes the total response solutions in one single run is far simpler than the modal analysis. Direct solution frees the analyst from the time consuming effort of computing and identifying the many vibrational modes to obtain the total response solution. Although the computing cost of direct solution is higher, the added cost is compensated by the saving in time and effort.

ACKNOWLEDGEMENTS

Figure 1.- Stac-Pac container.

+ EXPERIMENTAL   — NASTRAN

5.0 Hz EXCITATION   6.25 Hz EXCITATION
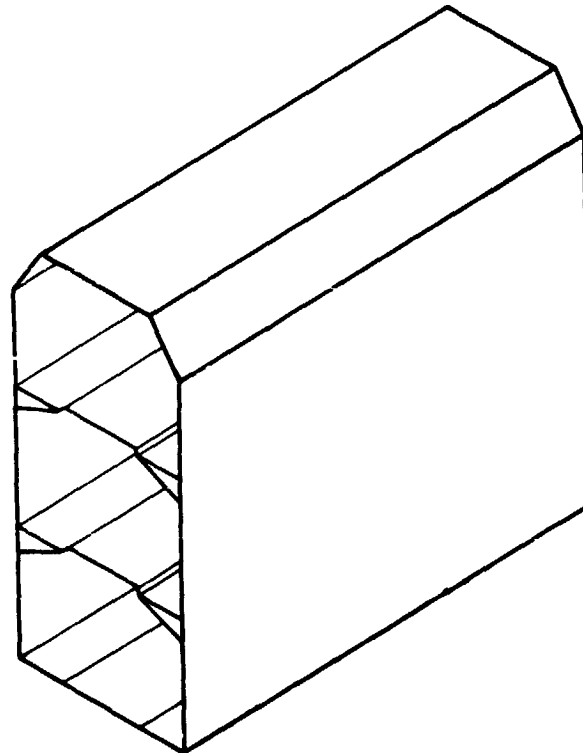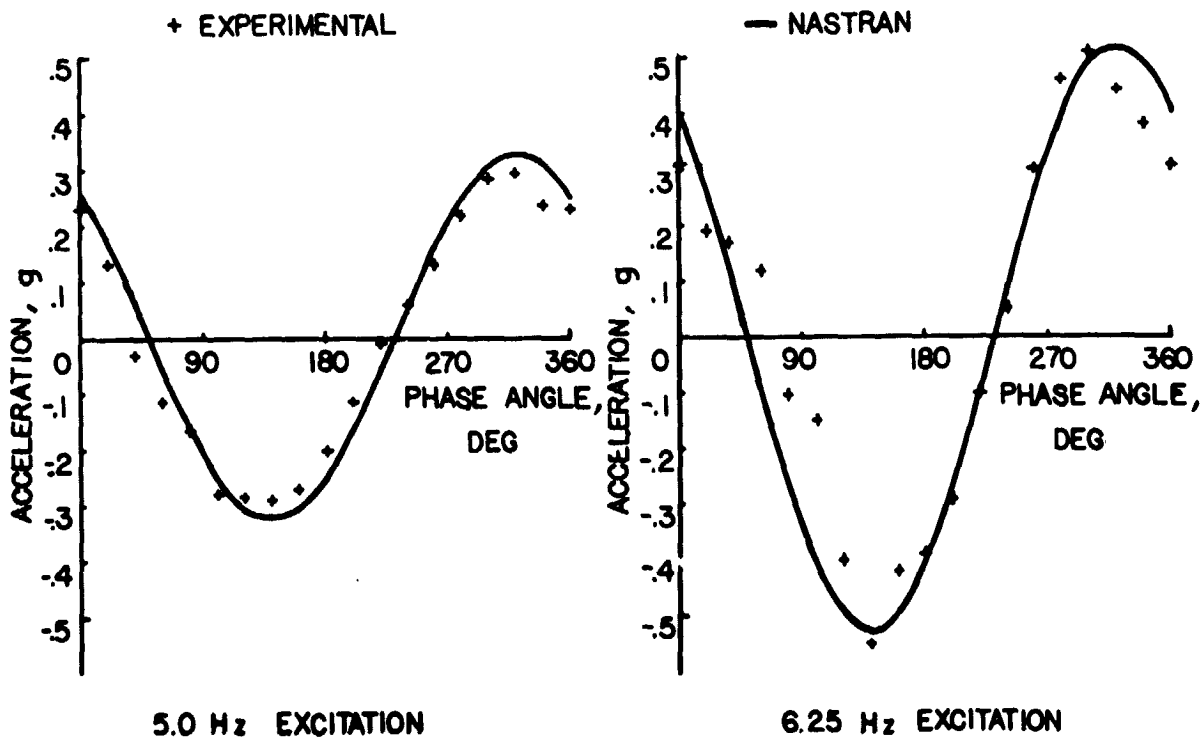
Figure 2.- Lateral acceleration of the container at 2nd deck.