SSC-259
(SL-7-6)

VERIFICATION OF THE RIGID VINYL MODELING TECHNIQUE:

THE SL-7 STRUCTURE

SHIP STRUCTURE COMMITTEE

1976

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ADDRESS CORRESPONDENCE TO:

Secretary
Ship Structure Committee
U.S. Coast Guard Headquarters
Washington, D.C. 20590

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This report is one of a group of Ship Structure Committee Reports which describes the SL-7 Instrumentation Program. This program, a jointly funded undertaking of Sea-Land Service, Inc., the American Bureau of Shipping and the Ship Structure Committee, represents an excellent example of cooperation between private industry, regulatory authority and government. The goal of the program is to advance understanding of the performance of ships' hull structures and the effectiveness of the analytical and experimental methods used in their design. While the experiments and analyses of the program are keyed to the SL-7 Containership and a considerable body of data will be developed relating specifically to that ship, the conclusions of the program will be completely general, and thus applicable to any surface ship structure.

The program includes measurement of hull stresses, accelerations and environmental and operating data on the S.S. Sea-Land McLean, development and installation of a microwave radar wavemeter for measuring the seaway encountered by the vessel, a wave tank model study and a theoretical hydrodynamic analysis which relate to the wave induced loads, a structural model study and a finite element structural analysis which relate to the structural response, and installation of long term stress recorders on each of the eight vessels of the class. In addition, work is underway to develop the initial correlations of the results of the several program elements.

Results of each of the program elements will be published as Ship Structure Committee Reports and each of the reports relating to this program will be identified by an SL- designation along with the usual SSC- number. A list of all of the SL- reports published to date is included on the back cover of this report.

This report is being issued as a special report in the SL-7 series of Ship Structure Committee Reports. The Ship Structure Committee appreciates the permission of the Navy to reprint this report which describes a study supported by the Naval Sea Systems Command with the Structures Department of the David W. Taylor Ship Research and Development Center to evaluate structural modeling techniques using rigid vinyl plastic as a modeling medium. The study was conducted utilizing data available from the SL-7 program. The data had been developed by the University of California under American Bureau of Shipping sponsorship using a steel model. Thus, this special report demonstrates a direct application of data developed during the SL-7 program which has led to an improved modeling technique for general application.

W. M. Benkert
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

SSC-259

(SL-7-6)

Special Report

VERIFICATION OF THE RIGID VINYL MODELING TECHNIQUE: THE SL-7 STRUCTURE

by

J. L. Rodd

Naval Ship Research & Development Center

under

Department of the Navy
NSRDC Project SR 023 0301
and
NSRDC Project SF 43 422 315

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U. S. Coast Guard Headquarters
Washington, D.C.
1976

ABSTRACT

The direct comparison of a rigid vinyl structural model with its steel counterpart under equivalent load conditions has been a prerequisite to the final verification of the rigid vinyl modeling technique. Such a program was completed and the resulting correlation described herein indicates that the structural response of a rigid vinyl model can be used to predict prototype characteristics effectively.

ADMINISTRATIVE INFORMATION

The work described herein was initiated under the Evaluation of Structural Analysis Techniques, Task Area No. SR 023 0301 and was completed under Structural Analysis for Advanced Monohull Ships, Task Area No. SF 43 422 315, both sponsored by the Naval Ship Systems Command, 0342.

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INTRODUCTION

A detailed structural model of the hydrofoil PLAINVIEW (AGEH-1) was constructed of rigid vinyl and instrumented as recorded in Reference 1.* Strain and deflection data was obtained during static loadings and the results showed favorable correlation with full scale trials data as reported in Reference 2. The prototype AGEH-1 is illustrated with the rigid vinyl model in Figure 1.

The rigid vinyl modeling technique accurately predicts the static response of a structure of different material and size if the applied loads are properly scaled and duplicated on the model. However, only the smooth water "1g" level flight data of the prototype AGEH-1 was usable for comparison with the model as it represented a predictable loading configuration. A more rigorous comparison of the rigid vinyl structure and its metal counterpart was desired to confirm this method of analysis.

In order to further verify the rigid vinyl modeling technique it was desired to correlate experimental data from a rigid vinyl ship model with that of a steel or aluminum model of similar geometry under identical loading configurations. Rather than build both models required for this verification it was decided that a steel structural ship model already in existence would be duplicated in the rigid vinyl material. The experimentation would then be simply a scaled version of that performed on the steel model, and a direct comparison of data from corresponding gage locations in each model would yield the desired correlation without excessive data reduction.

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*References are listed on page 13.

THE MODELS

The information required for the duplication of a model and its experimentation program was most readily available from a small scale steel structural model of the Sea-Land SL-7 containership. The University of California constructed and tested this model to satisfy the requirements of the Ship Structures Subcommittee in the verification of a computer analysis of the prototype SL-7 containership. The use of the steel model as a subject for data correlation provided an excellent test of the rigid vinyl modeling technique in that the structure represented is quite unconventional and demands proper modeling procedures to ensure correct response.

The nature of containerized transportation is such that the structural accomodations must tolerate an absence of major decking as illustrated in Figure 2. Torsional hydrodynamic loads would tend to induce large deformations in this type of "canoe-like" structure if the torsional stiffness had not been increased by such additions as longitudinal bulkheads, a double bottom, and torsion boxes. These features are depicted in the containership drawing of Figure 2. The SL-7 steel model incorporated these details to assure faithful response of the model to statically applied torsional loads. All structural features of the steel model were carefully reproduced in the rigid vinyl material to assure identical response characteristics of the two models. Figure 3 indicates the frame locations for reference and Figures 4 and 5 respectively illustrate the SL-7 rigid vinyl model and the SL-7 steel model after installation into the load fixtures.

The steel structure was modeled after the 950 foot prototype to a scale of 1:50 resulting in an overall model length of 19 feet. However, practical limits on welding procedures required the plating thickness to be increased by a factor of 3.0 throughout the model. Scaling relationships for static structural models are taken from Reference 1 and presented in Table 1. The increased thickness of the steel model is reflected in this table by the factor K which is defined as the ratio of the increased thickness to the true-to-scale thickness. For reasons of convenience the rigid vinyl model was designed to be half the steel model size, resulting in a 9.5 foot model with thicknesses scaled directly from the steel model. The relationships of Table 1 can be used to relate the rigid vinyl model parameters to those of the steel model simply by regarding the steel model as "prototype" while the rigid vinyl model is considered "model." Calculations relating the rigid vinyl model to the steel model according to Table 1 must be made using the K factor equal to unity. For clarity, the scaling relationships between the SL-7 steel model and the SL-7 rigid vinyl model are given in numerical form in Table 2. Appendix A contains information of value when relating the prototype, the steel model, and the rigid vinyl model of the SL-7 containership.

To assure similar behavior of the two models, the hull shape of the steel model was duplicated exactly. To minimize construction difficulties, the steel model was fabricated with a simplified hull geometry, resulting in a faceted surface of nearly flat plates. The rigid vinyl hull was constructed by thermoforming the material over a wooden mold with the same geometric simplifications as the steel model hull but with the result that the local effects of the welded joint discontinuities were not present. Figures 6 and 7 illustrate the structural details and joints of the steel model and the rigid vinyl model respectively from the same viewpoint. The completed stern section of each model is shown for comparison in Figures 8 and 9. The installation of the loading frames of the steel model had not yet been completed at this stage. However, the rigid vinyl model counterparts of these are shown clearly in Figure 9. It is noteworthy that the SL-7 prototype could have been modeled in rigid vinyl with greater detail and more representative hull shape than was possible using steel as the material.

INSTRUMENTATION

The instrumentation of the steel model was duplicated on the rigid vinyl model such that a direct comparison of experimental results could be made without excessive data reduction. Each strain gage was positioned on the rigid vinyl model in the same manner as its corresponding gage on the steel model. Of the total 180 strain gages, 111 gages comprised the 37 rectangular rosettes. The majority of the remaining single gages were installed in the longitudinal direction. The instrumentation between frames 178 and 194 of each model is shown for comparison in Figure 10. Angle of twist measurements were taken on the rigid vinyl model by means of a pendulum inclinometer positioned at various points along the model as shown in Figure 9. The dial gages used for these readings on the steel model can be seen in Figures 10 and 11.

EXPERIMENTAL PROCEDURE

The loading apparatus of the steel model consisted of the load frame and pulley system shown in Figures 11 and 12. The weights required for some of the steel model loads totaled several thousand pounds resulting in heavy supporting structures and difficult testing procedures. The equivalent apparatus used for application of static loads on the rigid vinyl model is illustrated in Figure 13. A measured quantity of lead shot was sealed in each polyethylene bag and labelled with the correct test number and location to facilitate loading operations. The required weights were attached to the loading arms of the model and then placed on the load frame tabletop until the model was to be loaded. After initial zero load readings had been obtained the weights were lowered and a second reading of the gages was taken. The difference between these two readings represents the net effect of the static load applied to the model. In Figure 13 the junction boxes used to interface the model instrumentation to the automatic data acquisition system are shown beneath the load frame tabletop. The junction boxes provide a complete bridge network for each gage and voltage information is available to the computer for immediate data reduction and printout. Further reduction by hand is not necessary as stresses are recorded in equivalent steel model values. A direct comparison of the steel and rigid vinyl models was quickly made by plotting stresses obtained from each model at corresponding gage locations.

LOADING SCHEDULE

The basic static load configurations applied to the two models are shown in Figure 14. The rigid vinyl model was subjected to eight different experiments, five of which provided information on the torsional response of the structure. Table 3 formally lists the experiments performed on the rigid vinyl model. A direct scaling of the loads applied to the steel model resulted in the rigid vinyl model loads used for tests 1 through 5. The stresses obtained from the longitudinal gages of the steel model during these particular tests were available as plotted information, thus constituting the primary data correlation of the models. The remaining experiments provided information on the angle of twist the structure experienced during three related torsional loads. The loads applied to the steel model and the rigid vinyl model during experiments 1 through 5 are given in Table 4. Included in this table is a plan view of the structure with frames marked for reference. In actuality, the negative torsion test performed on the steel model included weights of half the values used in the positive torsion test. However, the full values of the loads presented in Table 4 were applied to the rigid vinyl model during both the positive and the negative torsion experiments. Equivalent prototype loads for all experiments can be found as indicated in Appendix A.

RESULTS AND DISCUSSIONS

The longitudinal stresses observed at corresponding gage locations on the steel model and the rigid vinyl model were plotted together for convenient illustration. Similarities and differences in the two models are most easily presented by the use of three-dimensional drawings of the heavily instrumented areas of the ship structure. The stresses observed on the two models are plotted alongside the structure in these drawings as shown in the key in Figure 15. The titles of Figures 16 through 24 indicate the load condition and structure location for each stress plot. It must be emphasized that the stress scale is not the same in all of these drawings and that all plotted stresses have been converted to steel model equivalents for convenience. Any manipulation of this data to study prototype behavior must be done so according to Appendix A.

Only a limited number of representative plots are included herein to maintain a concise report. It was noted that the positive and negative torsion stresses were nearly identical in magnitude and opposite in sign; therefore only the positive torsion data is presented. Since the close agreement of the stresses observed on each structure is visually apparent, only the noteworthy differences will be discussed. Figures 16 through 18 illustrate the typical stresses induced in a ship structure by a hogging moment. The steel model data differs from the rigid vinyl model data at the corners or chines of the hull bottom. At these gage locations throughout the structure, the steel model exhibits a consistently higher stress than the rigid vinyl model. This is true of the gages at longitudinal bulkhead joints as well. It is believed that the increased stress at these points is due to a stiffening effect and possibly a stress concentration effect of the welds which lie directly under or near the gages. These welds appear grossly out of proportion when compared to the more scale-like joints of the rigid vinyl model as shown in Figures 6 and 7. The spot welding of strips of steel to the torsion boxes of the steel model was done to increase bending stiffness without significantly affecting the torsional stiffness. Regardless of prototype characteristics it was desired to duplicate the steel model construction as nearly as possible. Accordingly, it was decided to simulate the torsion box spot welding by the epoxy welds shown in Figure 7. These joints appeared to perform satisfactorily.

A major discrepancy between the two models occurred at frame 290 near the bow during the torsional experiments. As illustrated in Figure 22, the rigid vinyl model stress at the hatch corner exceeded the steel model stress by a significant amount. However, at the gage location next to this the steel model stress was the higher of the two. Further investigation of this anomaly revealed several characteristics of both prototype behavior and model behavior. The high stress level observed at this corner is due to three major causes: warping stresses due to the torsional load, an abrupt change in the torsional stiffenss at this point, and the stress concentration of the corner itself. The resulting high stress gradient shown in Figure 22 adversely affects the faithfulness of the models in this area. Any small differences in the location of the gages, the application of the applied loads, or the modeled structures can change the flow of stresses at the hatch corner. This results in large differences in the observed stresses simply because of the high gradient of the stress curve. The four data points shown at the top of Figure 22 indicate approximately the stress level experienced by the structure at the hatch corner, but the dispersion of the points is large. Closer agreement could probably not be obtained by two "identical" rigid vinyl structures or by two "identical" steel structures. In all structural modeling efforts, great care should be taken when drawing conclusions from data in areas of high stress gradient.

The remaining three experiments were performed as described in Table 3 to observe the angle of twist experienced by the structure under various torsional loads. The applied loads of experiment 6 were scaled directly from a corresponding steel model test. No appreciable angles were observed on the rigid vinyl model although results of the steel model tests claimed twist angles of more than eight degrees. Cursory examination of the steel model data indicates dial gage calculations to be at fault. Informal reports of the SL-7 prototype torsional behavior claim negligible angle of twist readings as predicted by the rigid vinyl model.

To induce measurable twist angles, the highest allowable torsional load was applied to the rigid vinyl model in the last two experiments. It was found that no harmful stresses would be developed in the rigid vinyl ship structure by a torsional moment of 140 in-lbs. This torque was achieved by five-pound loads applied upward and downward at four points on the model. Load frames were strengthened to accomodate these heavy local loadings without buckling. Again, no measurable twist angles were developed, even though these loads correspond to actual cargo shifts of seven thousand tons in a transverse direction at two points on the prototype to achieve this torsional load. These loads were applied to the rigid vinyl model in two ways to determine if the stresses were affected by differences in the model supports. First, in experiment 7, the model was hung by the original supports designed to simulate those of the steel model. Then, in experiment 8, the model was freely hung by the upward load cords, thus eliminating the supports and inducing a pure torsional load to the structure. No apparent differences were observed in the angle of twist readings or in the stresses.

The area of high stress gradient at the hatch corner of frame 290 was carefully observed during the angle of twist experiments. All experiments proved the high stresses of experiment 4 to be authentic. In addition, it was observed that these highest stresses were quite distant from any applied load. In other words, during torsional loadings the warping stresses can be such that the highest observed stresses of the entire structure can be found in areas of zero load. This is especially true when the resistance to warping deformations offered by the bow and stern contribute significantly to the torsional rigidity as in the SL-7 structure. Predictions of prototype stresses must be made cautiously if verification by structural model is not utilized. Unexpectedly high stresses can result from complex torsional phenomena as shown here. For example, the stresses of frame 290 during torsional loads was predicted by finite element techniques to be insignificant since no applied load was present at that frame. Yet, under negligible applied load during the torsional experiment, this area actually experienced the greatest stress encountered in the entire rigid vinyl model program.

ADDITIONAL OBSERVATIONS AND CONCLUSIONS

The direct comparison of geometrically similar structural models of rigid vinyl and steel under equivalent load conditions has been a prerequisite to the final verification of the rigid vinyl modeling technique. The experimental program of the SL-7 rigid vinyl model was successful in the accomplishment of this primary objective as well as informative in structural modeling procedures.

The results described herein indicate that essentially the same information was retrieved from the experimental programs of the steel model and the rigid vinyl model. The use of rigid vinyl as the modeling material reduces construction efforts, improves the representation of complex structural shapes and details, and offers reduction of experimental efforts due to ease of handling and convenient load magnitudes.

It was shown that modeling of structural joints must be done with care in areas which may affect strain gage results. Differences between the rigid vinyl and steel structures at joint discontinuities indicate that steel model welds may have a stiffening effect on the hull skin as recorded by nearby gages.

Analysis of torsional stresses on the two SL-7 models revealed that areas of high stress concentration or high stress gradient can be misrepresented by strain gage results simply because of the range of stresses present in a small area. It should be noted that actual prototype stresses may exceed the expected values determined by model experiments because of this effect.

Previous model experiments have established that longitudinal stresses are proportional to the bending moment at the frame under examination, regardless of the moment diagram over the rest of the structure. However, this convenience is not available for torsional investigations, since warping stresses are a function of the torsional load over the entire structure, as shown by the effects of the last two experiments on frame 290 of the SL-7 rigid vinyl model. In short, predictions by proportionality of stresses can be made only when the entire torsional load at all frames is related by a constant factor to some previous experiment.

In many ways the experimental program of the SL-7 rigid vinyl model has pointed out the advantages of structural modeling as well as some of the precautions to be acknowledged. The use of rigid vinyl as the modeling material has proved to be convenient throughout several model programs and has been shown to agree with steel model predictions through the comparison of two similar models of these two important materials. The rigid vinyl modeling technique is offered as a valuable tool for structural analysis.

ACKNOWLEDGEMENTS

The author is indebted to C. S. Loosmore, Lieutenant Commander, U. S. Coast Guard; Professor W. C. Webster, University of California at Berkeley; and Robert Johnson, Code 6128 NAVSEC for supplying information on the prototype SL-7 containership and the steel model. The rigid vinyl model was designed by Steven L. Austin, Code 173.6, NSRDC.

REFERENCES

1. Austin, S. L. "Design History of the Rigid Vinyl Model of the Hydrofoil PLAINVIEW (AGEH-1)" Structures Department Report 3883 (October 1972).

2. Austin, S. L. "Rigid Vinyl Model Prediction of PLAINVIEW (AGEH-1) Elastic Structural Response" Structures Department Technical Note n222 (August 1972).

APPENDIX A

The scaling relationships given in Table 1 were derived for static structural models only. Any two geometrically similar structures can be related by customarily referring to the larger as "prototype" and the smaller as "model". Note that the scale factor, λ, is defined as the ratio of model length to prototype length, which is contrary to some conventions. The relationships of Table 1 are written in terms of the scale factor λ, the ratio of elastic moduli e, the ratio of shear moduli g, and the thickness factor K. The following simplifies the procedure for relating the SL-7 prototype and model parameters.

1. Relating the steel model to the rigid vinyl model.

   $\lambda = 0.5$, $e = 0.0167$, $g = 0.0167$, $K = 1.0$

   (Table 2 gives these relationships numerically).

2. Relating the prototype SL-7 to the steel model.

   $\lambda = 0.02$, $e = 1.0$, $g = 1.0$, $K = 3.0$

   (Table 1 is to be used with these values).

3. Relating the prototype SL-7 to the rigid vinyl model.

   $\lambda = 0.01$, $e = 0.0167$, $g = 0.0167$, $K = 3.0$

   (Table 1 is to be used with these values).

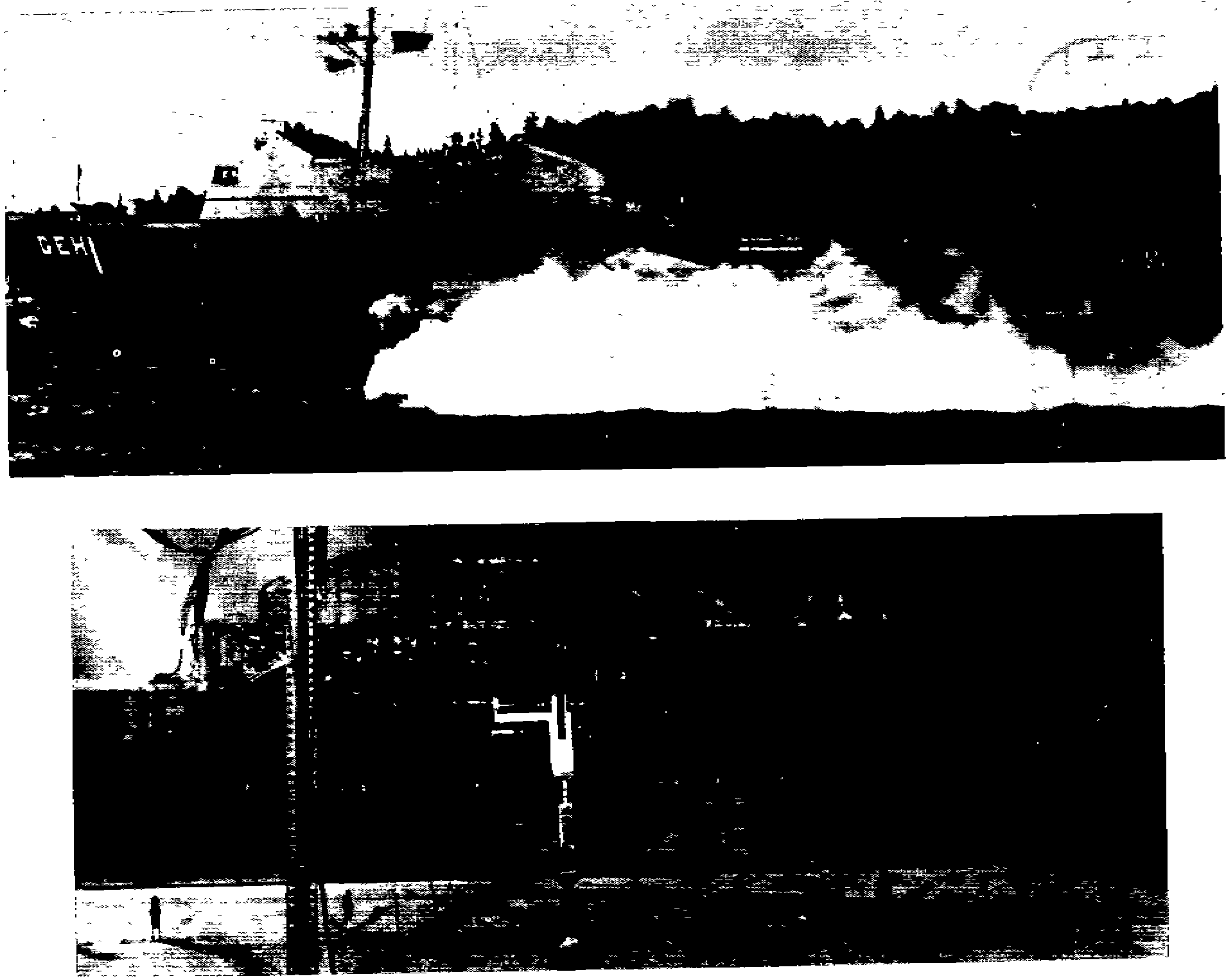
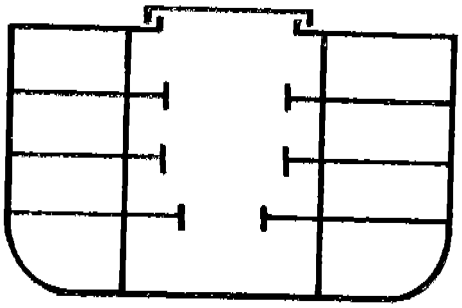
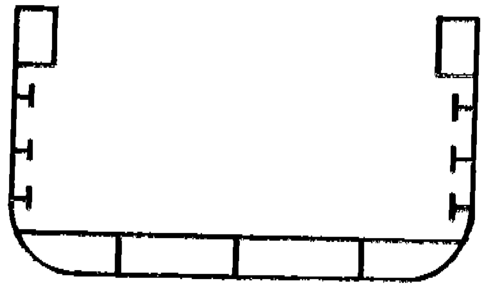


FIGURE 1 - Plainview (AGEH-1) Prototype and 1:20 Scale Rigid Vinyl Model





Cargo Ship

Containership

FIGURE 2 - Typical Midship Sections of Cargo Ship and Containership Structures

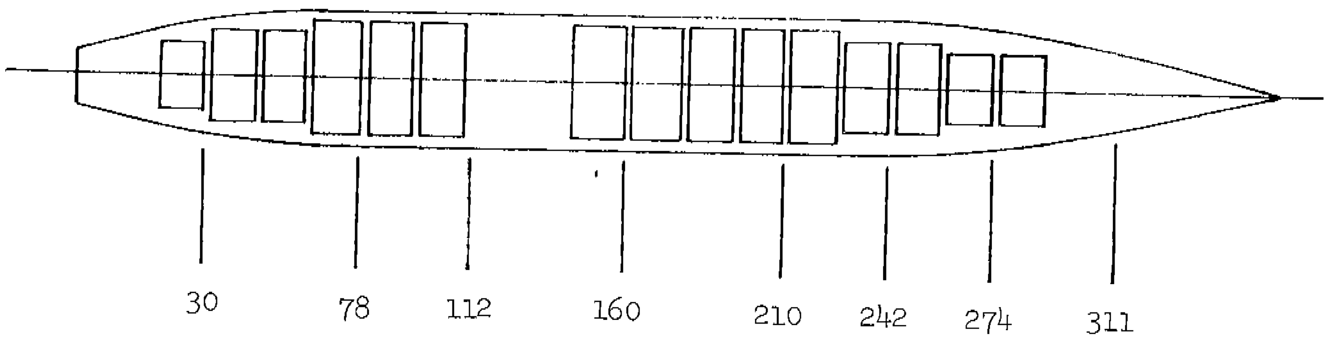


Figure 3 - SL-7 Frame Locations

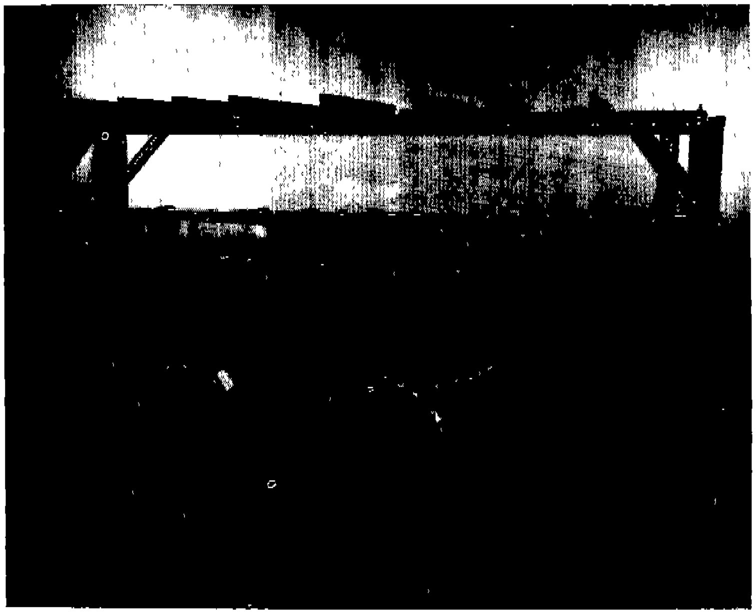


FIGURE 4 - The 1:100 Scale Rigid Vinyl Model of the SL-7 Containership

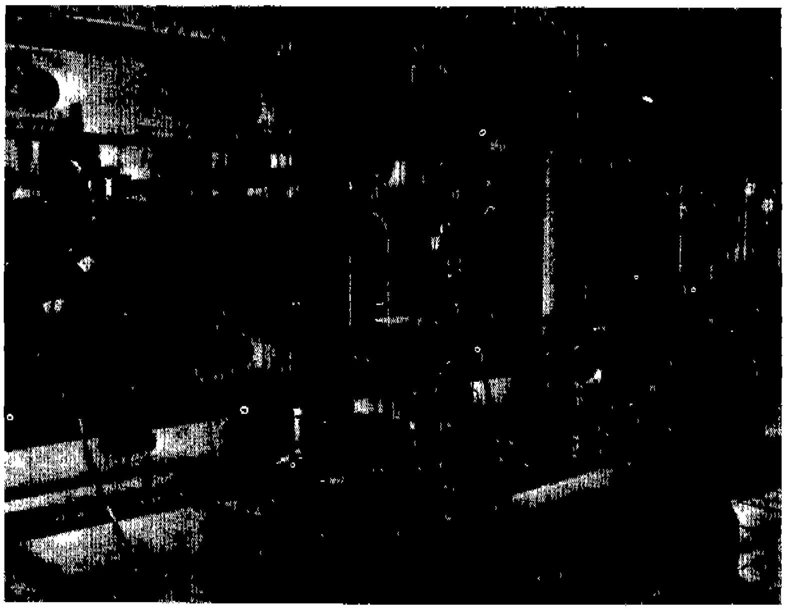


FIGURE 5 - The 1:50 Scale Steel Model of the SL-7 Containership

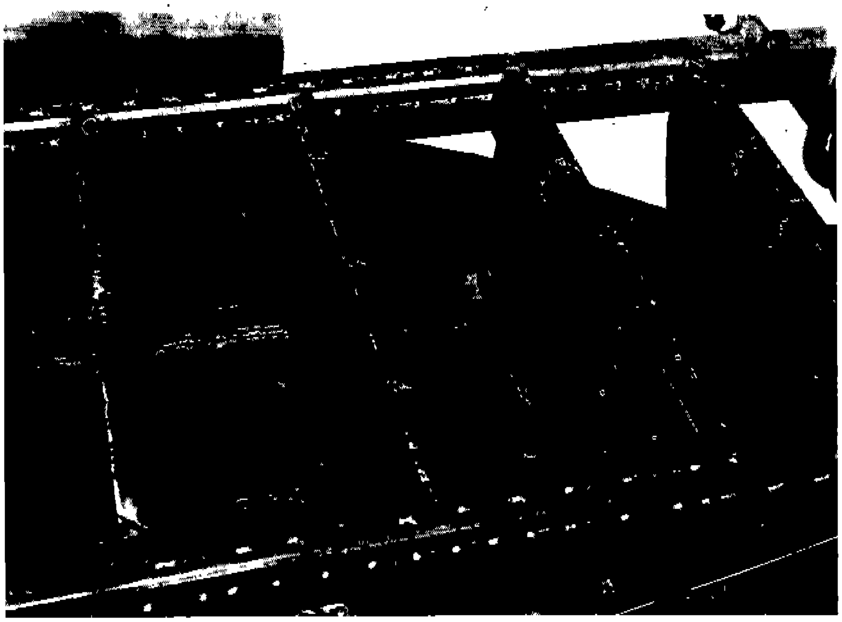


FIGURE 6 - Details of the SL-7 Steel Model during Construction

FIGURE 7 - Details of the Completed SL-7 Rigid Vinyl Model

FIGURE 8 - Completed Stern Section of the SL-7 Steel Model

FIGURE 9 - Completed Stern Section of the SL-7 Rigid Vinyl Model

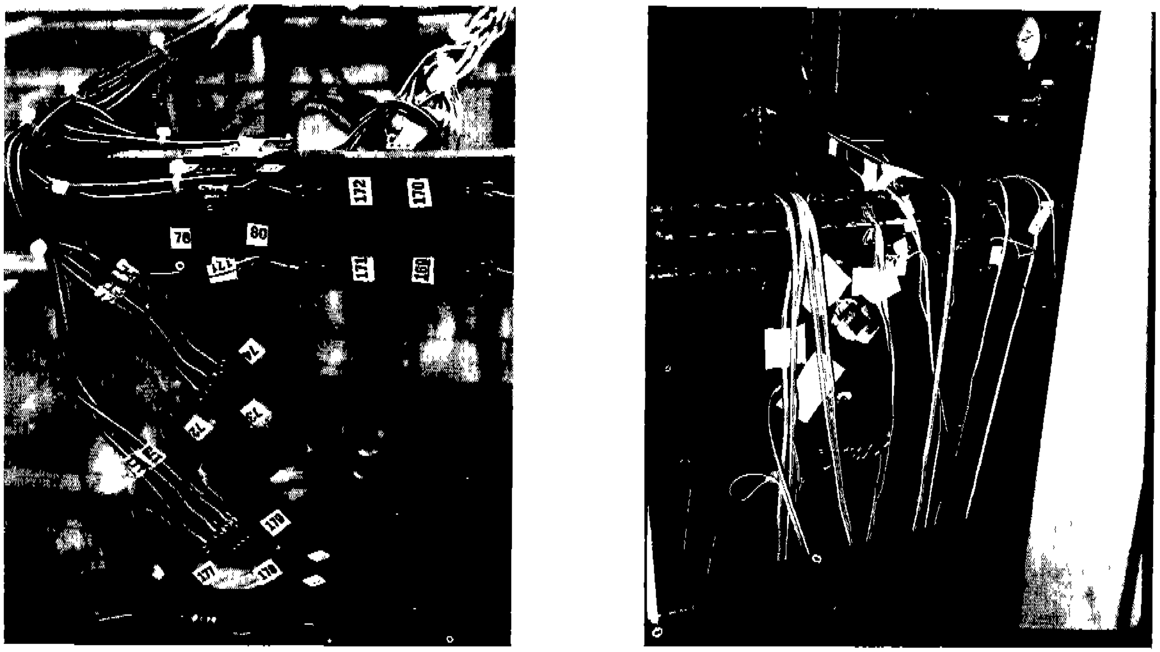


FIGURE 10 - Comparison of Strain Gage Locations on the SL-7 Rigid Vinyl Model and on the SL-7 Steel Model

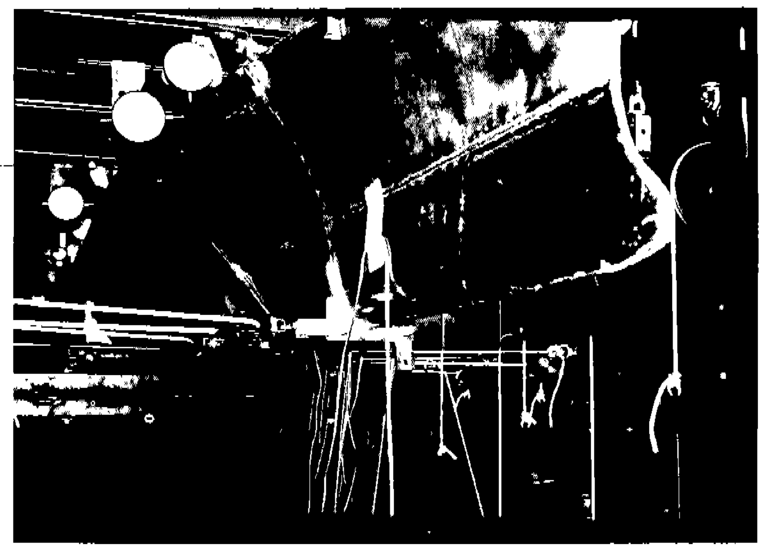


FIGURE 11 - View of Hull and Loading Apparatus of the SL-7 Steel Model

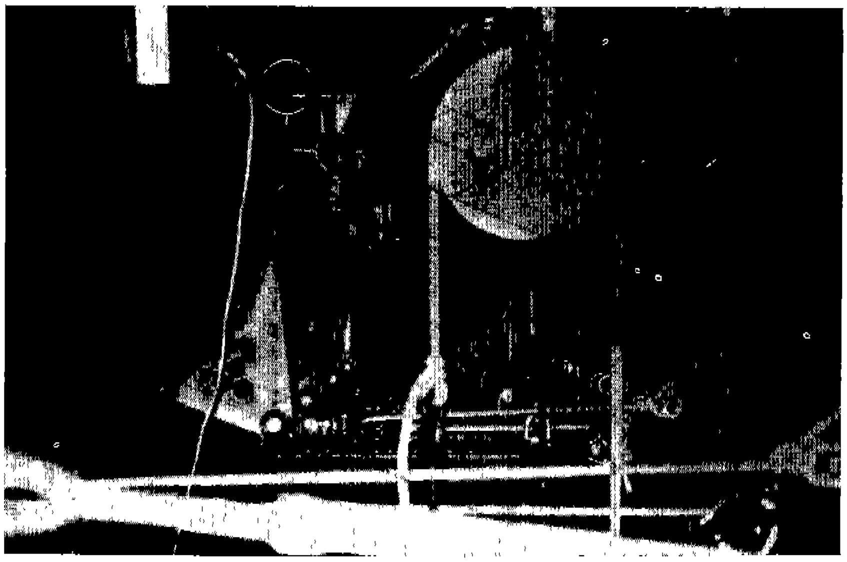


FIGURE 12 - View of Loading Apparatus of the SL-7 Steel Model

FIGURE 13 - View of Hull and Loading Apparatus of the SL-7 Rigid Vinyl Model

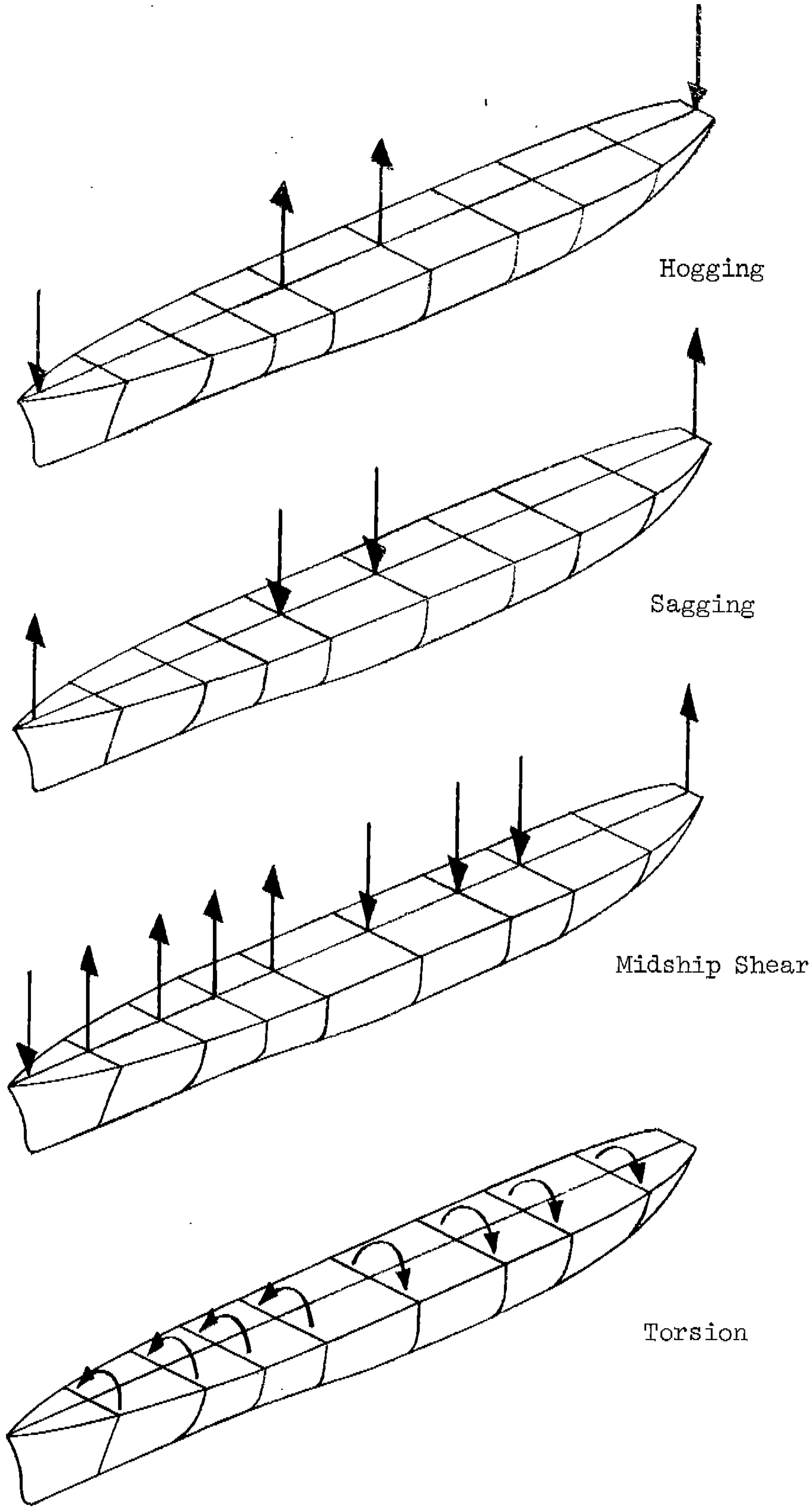


FIGURE 14 - Static Loads Applied to the SL-7
Steel and Rigid Vinyl Models

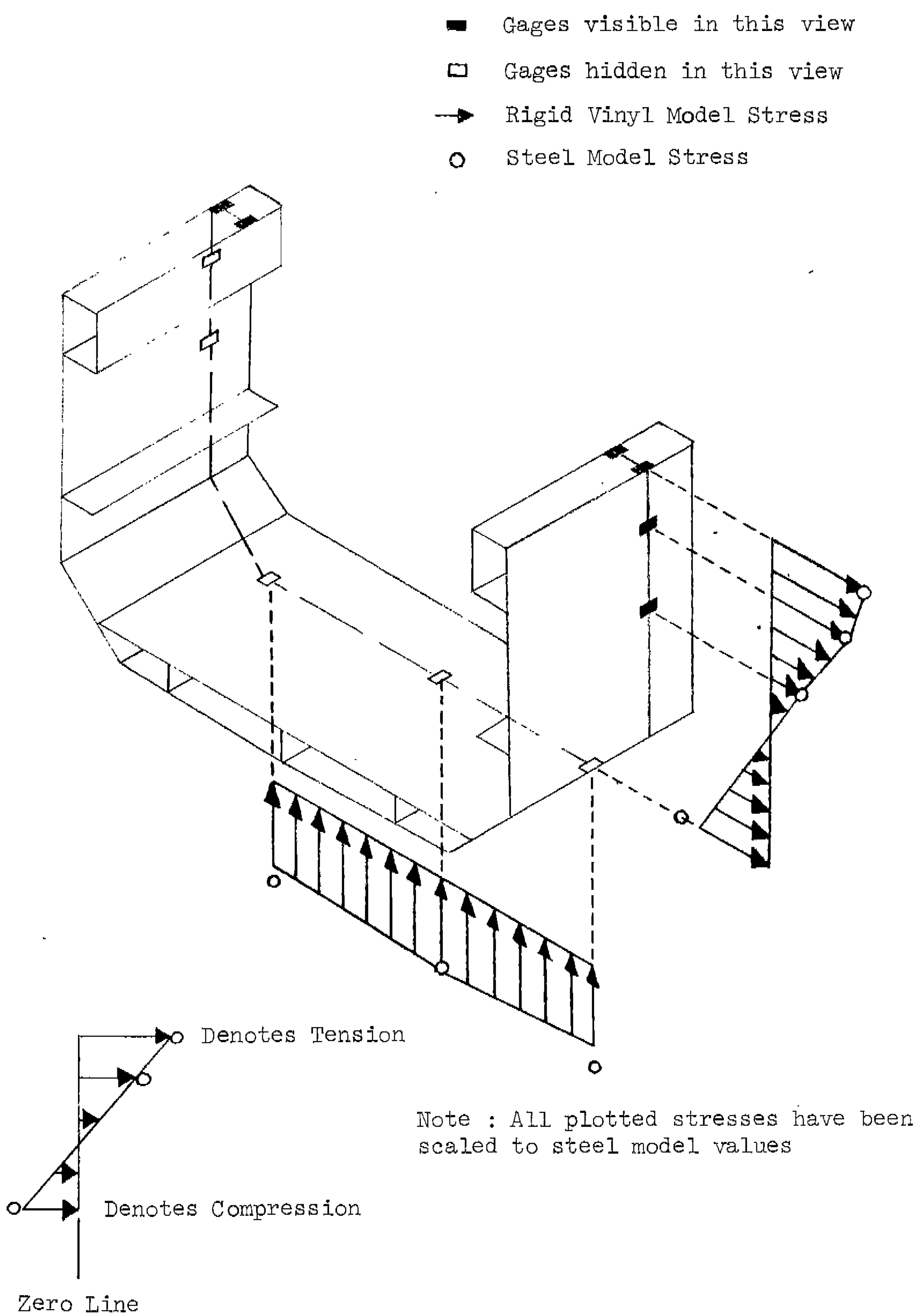
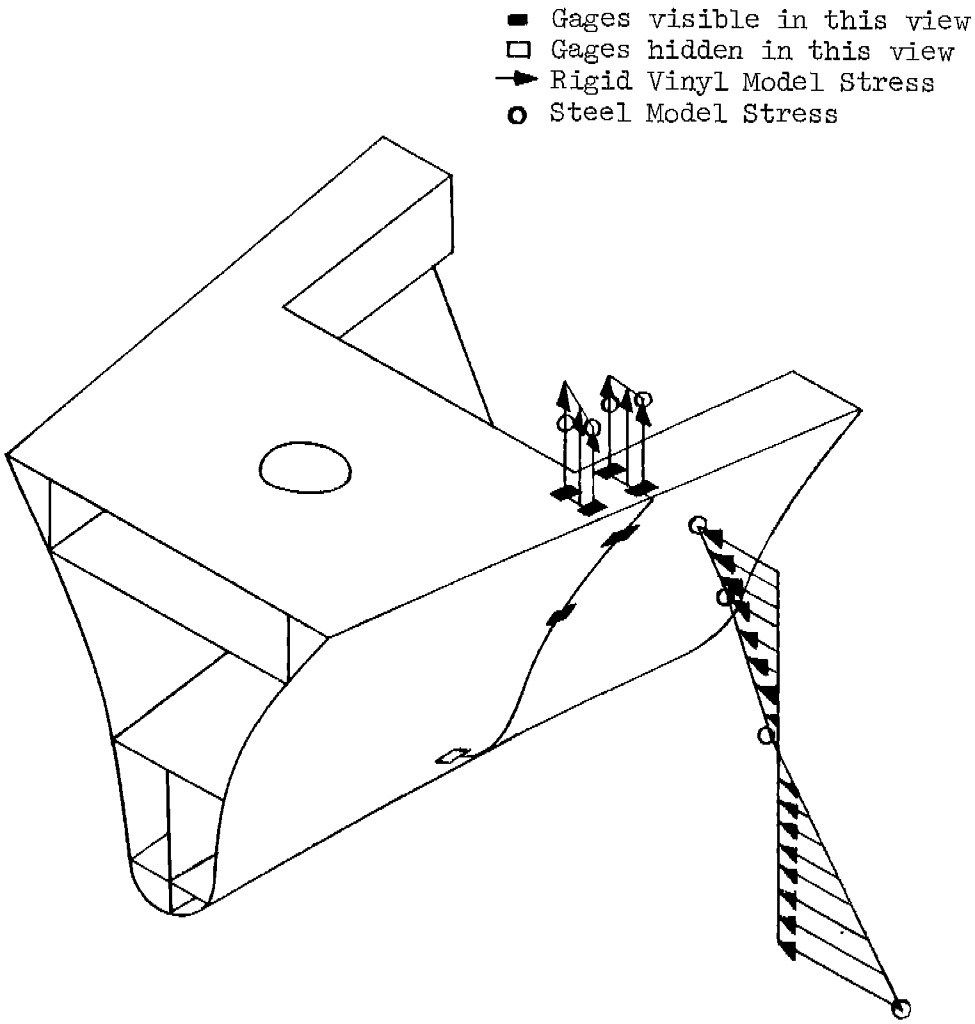


FIGURE 15 - Key to Figures 16 through 24



Stress Scale 1" = 8 KSI

FIGURE 16 - Comparison of SL-7 Stresses at Frame 290
during Large Hogging

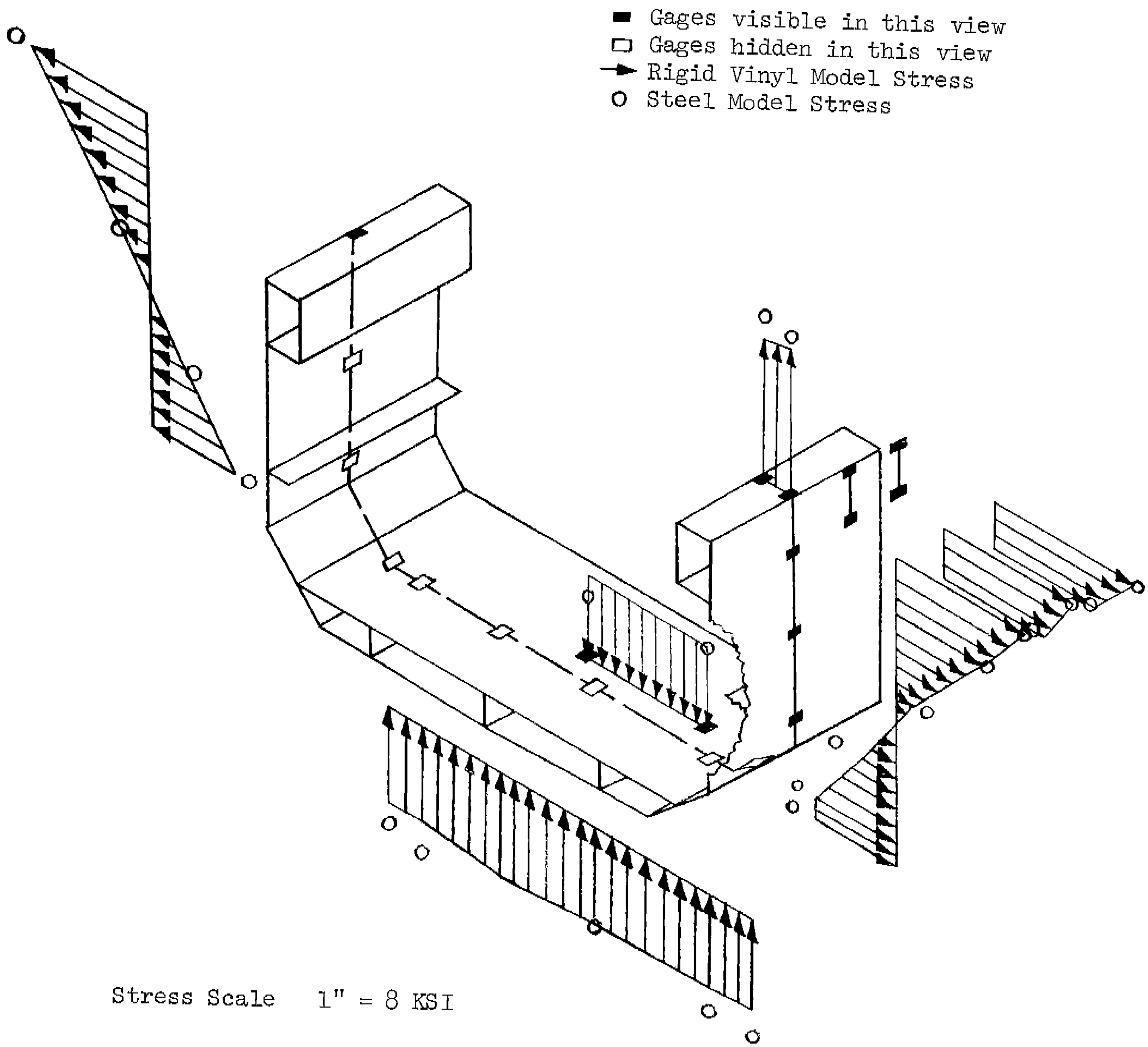


FIGURE 17 - Comparison of SL-7 Stresses at Frame 178 during Large Hogging

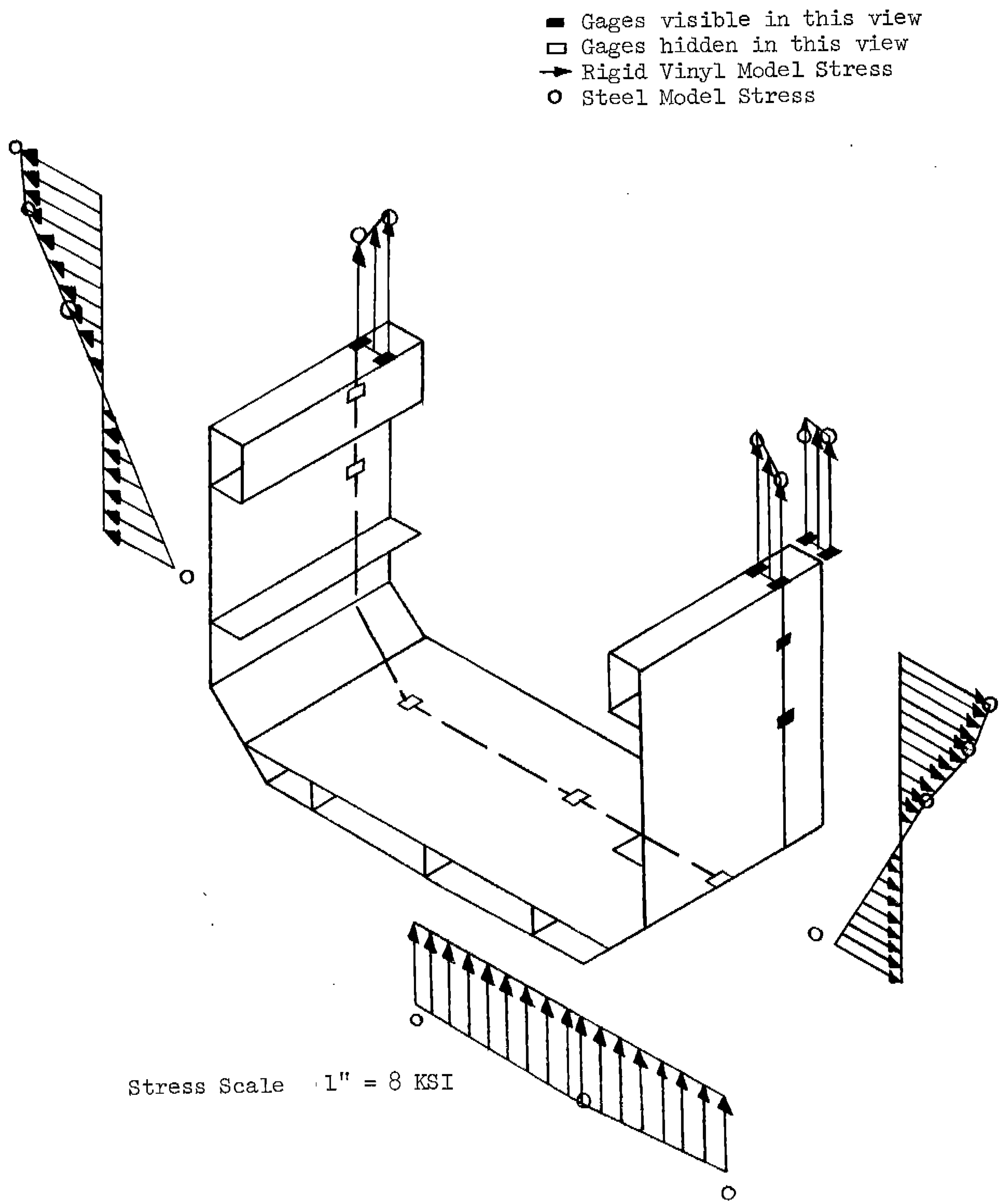


FIGURE 18 - Comparison of SL-7 Stresses at Frame 142
during Large Hogging

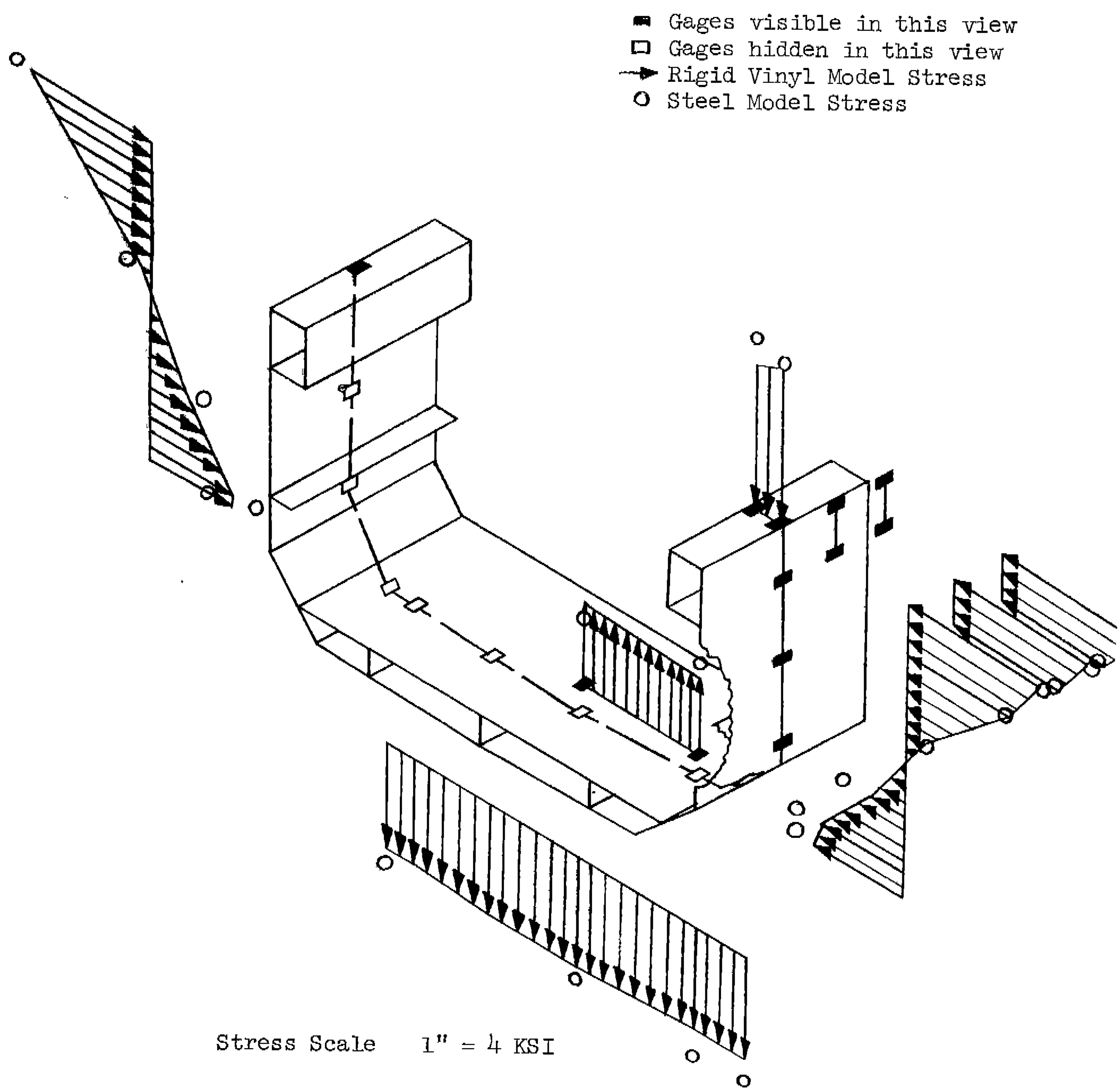


FIGURE 19 - Comparison of SL-7 Stresses at Frame 178 during Half Sagging

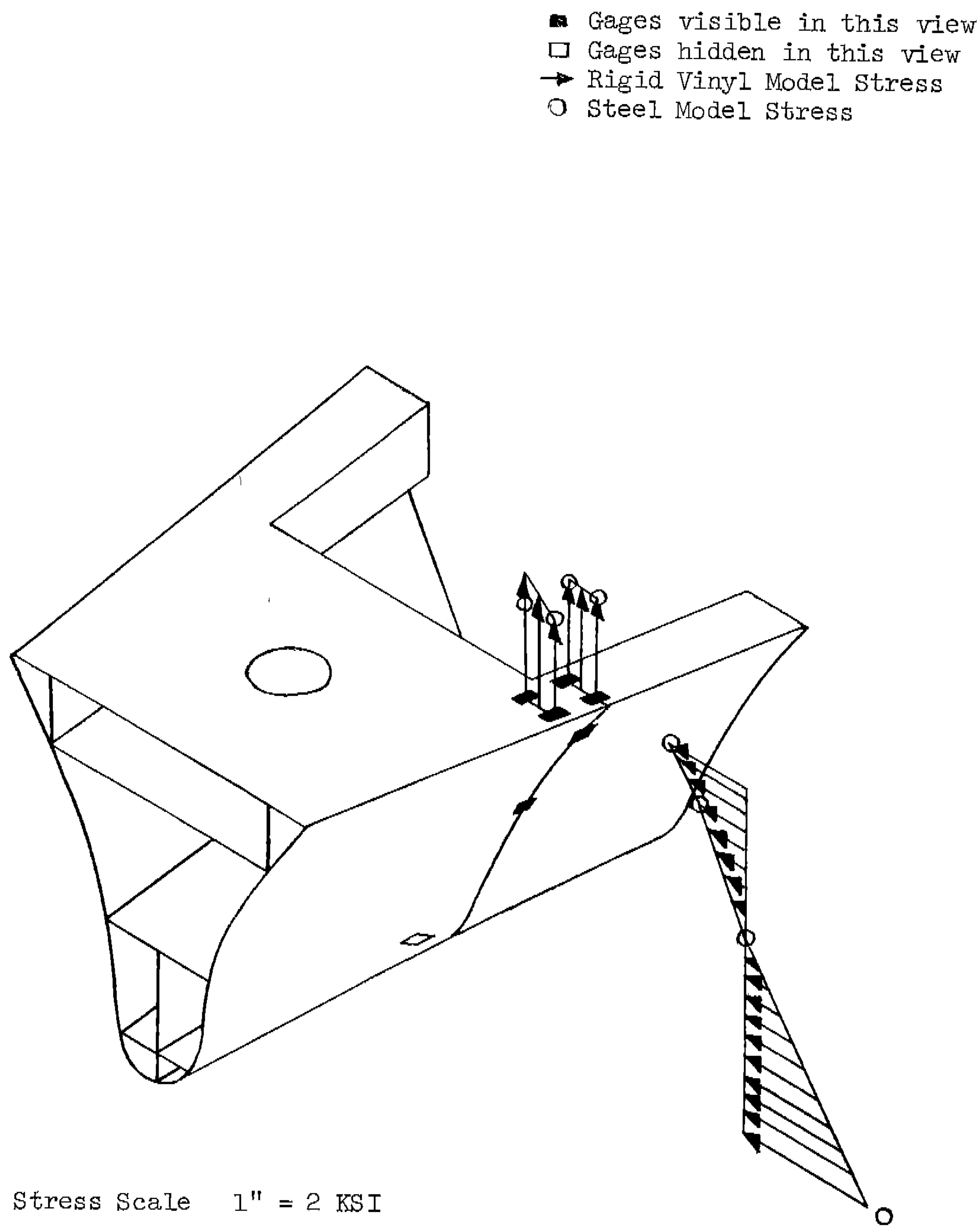


FIGURE 20 - Comparison of SL-7 Stresses at Frame 290
during Midship Shear

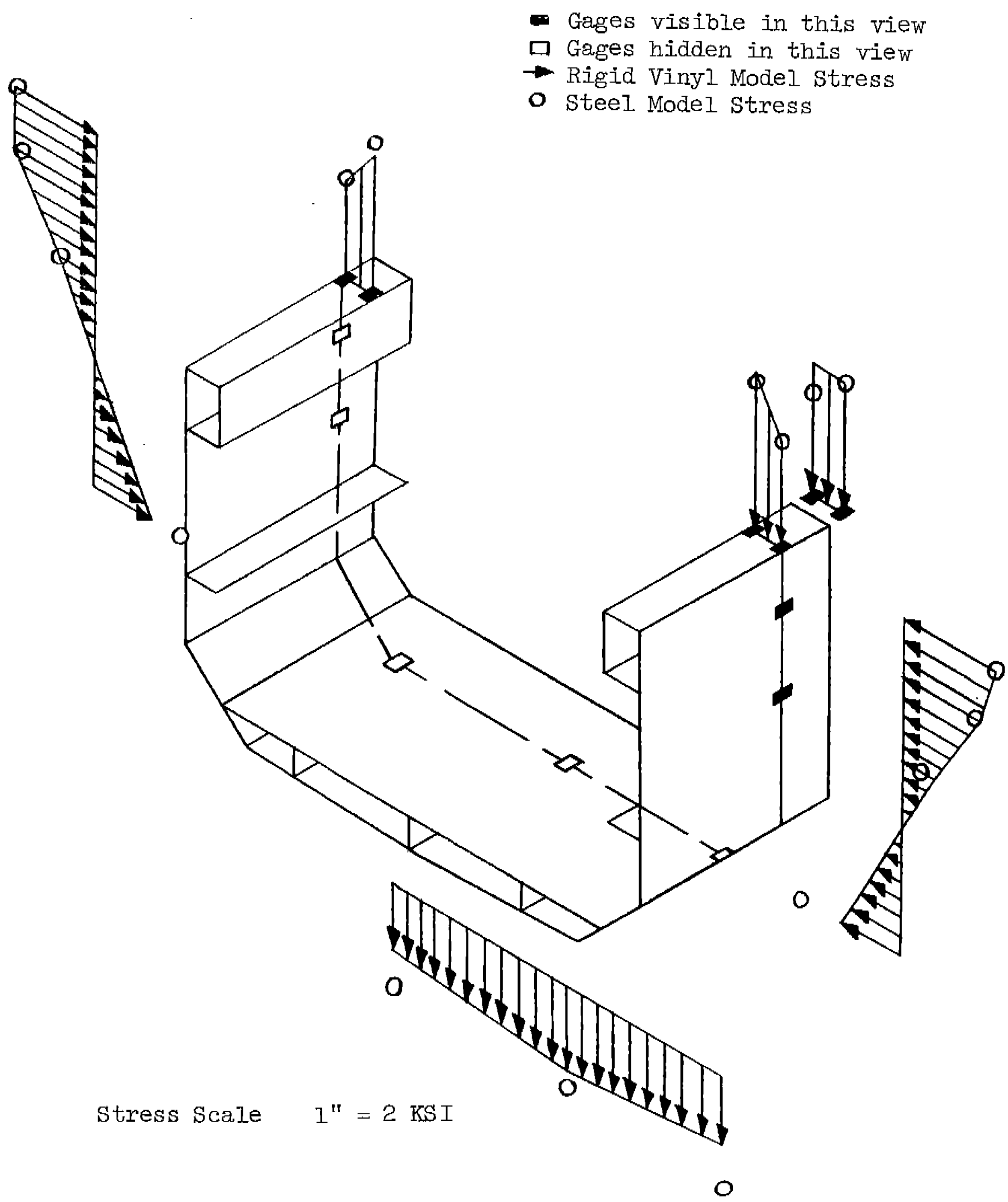


FIGURE 21 - Comparison of SL-7 Stresses at Frame 142
during Midship Shear

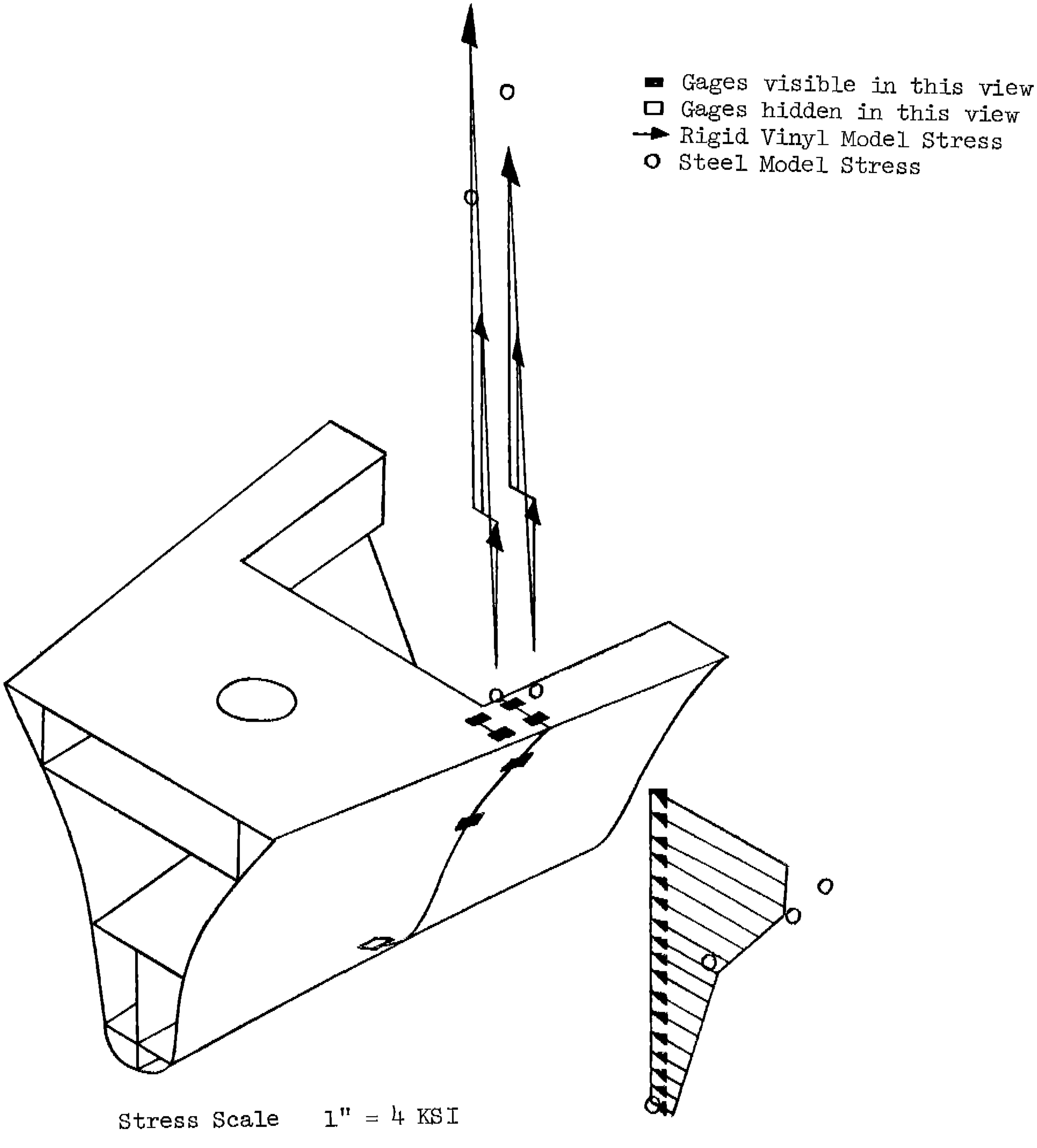


FIGURE 22 - Comparison of SL-7 Stresses at Frame 290
during Positive Torsion

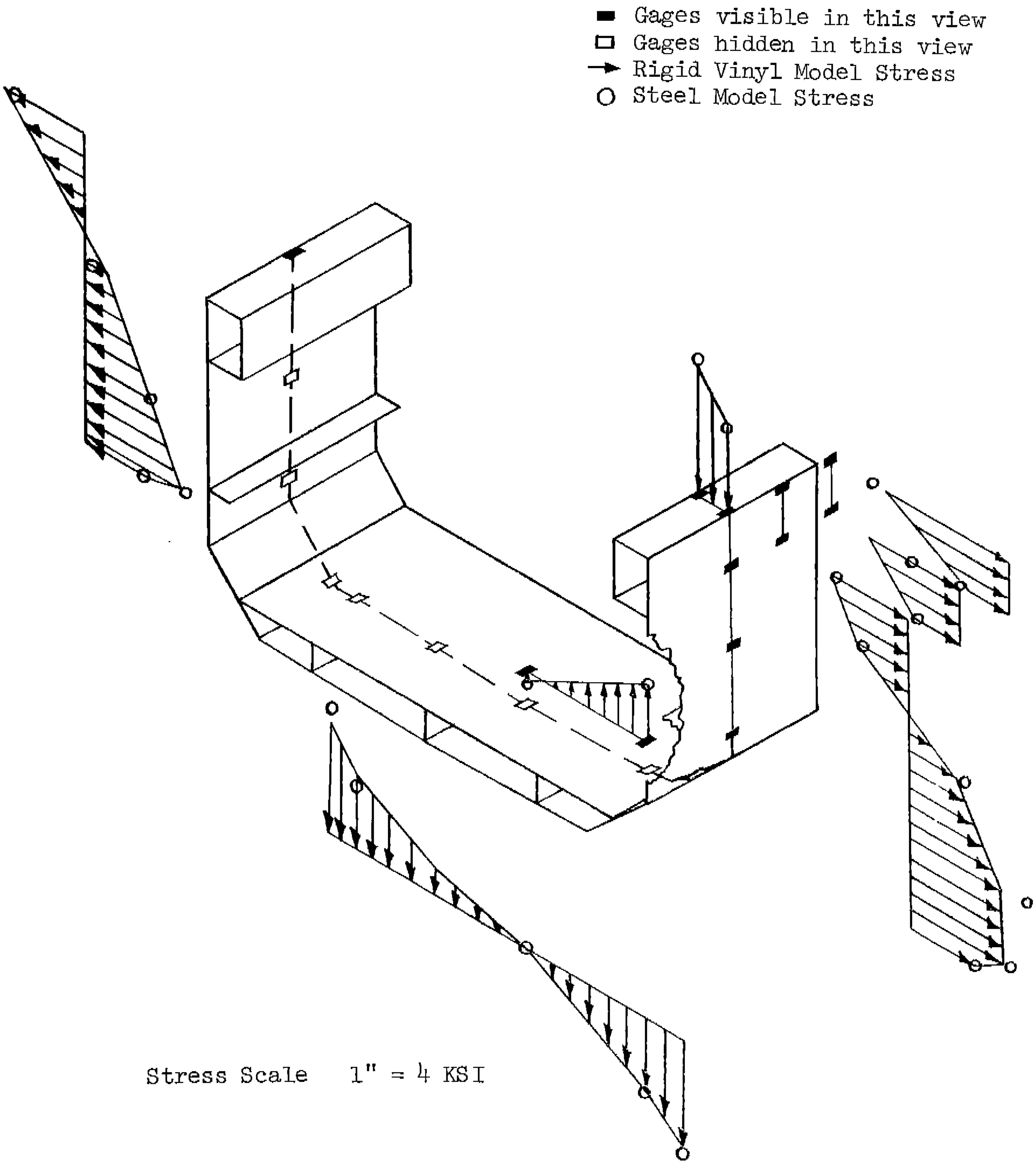
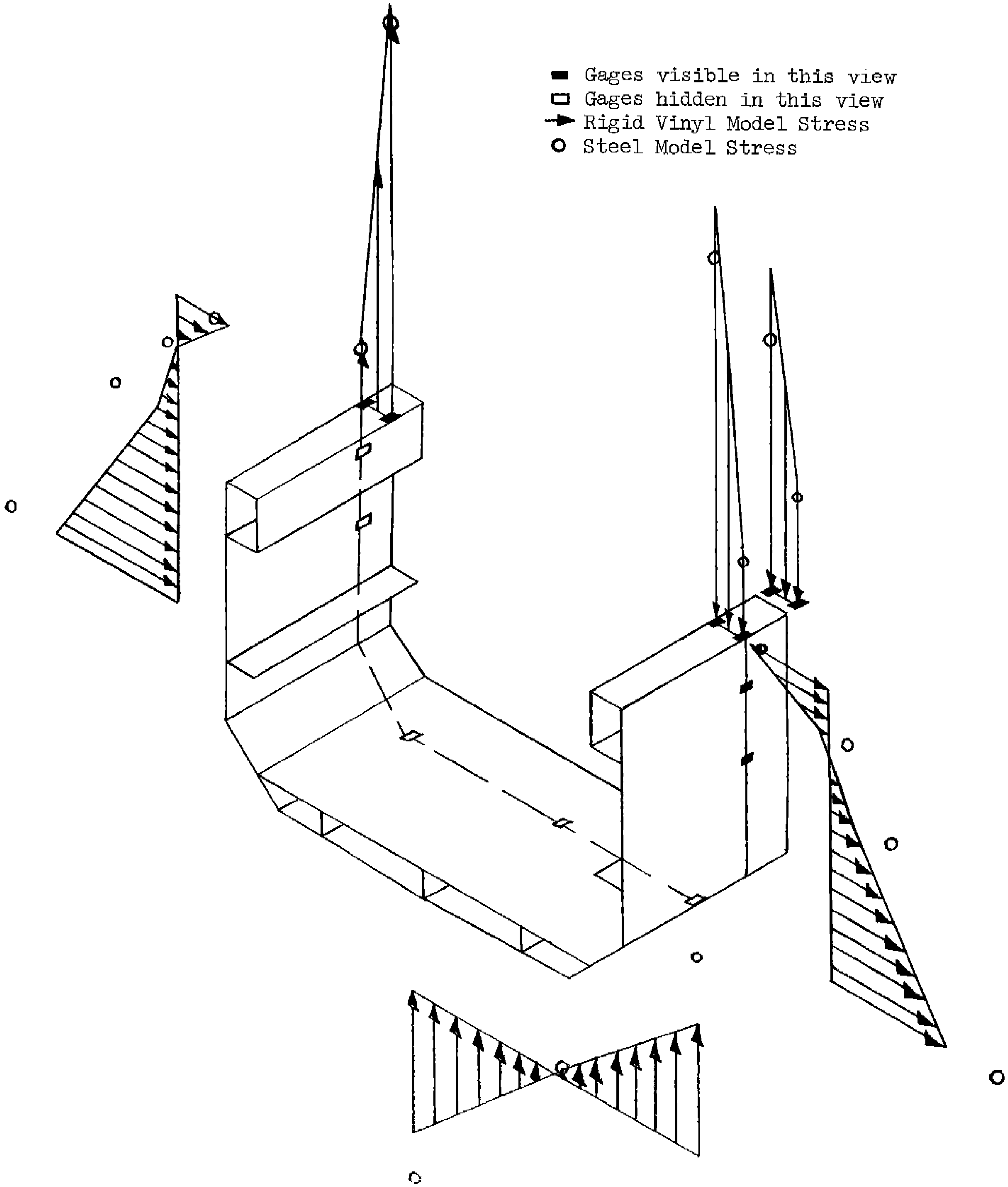


FIGURE 23 - Comparison of SL-7 Stresses at Frame 178
during Positive Torsion



Stress Scale 1" = 4 KSI

FIGURE 24 - Comparison of SL-7 Stresses at Frame 142
during Positive Torsion

TABLE 1 - Scaling Relationships for Static Structural Models

Measured Quantity	Prototype	Model
Length	L_p	$L_m = \lambda L_p$
Strain	ε_p	$\varepsilon_m = \varepsilon_p/K$
Stress	σ_p	$\sigma_m = e\sigma_p/K$
Force	F_p	$F_m = \lambda^2 e F_p$
Moment	M_p	$M_m = \lambda^3 e M_p$
Moment of Inertia	I_p	$I_m = K\lambda^4 I_p$
Section Modulus	S_p	$S_m = K\lambda^3 S_p$
Polar Moment of Inertia	J_p	$J_m = K\lambda^4 J_p$
Torque	T_p	$T_m = \lambda^3 e T_p$
Shear	τ_p	$\tau_m = e\tau_p/K$
Unit Angle of Twist	θ_p	$\theta_m = e\theta_p/K\lambda g$
Total Angle of Twist	ϕ_p	$\phi_m = e\phi_p/Kg$
Axial Deformation	δ_p	$\delta_m = \lambda\delta_p/K$

Note: In the above relationships,

$\lambda = L_m/L_p$

$e = E_m/E_p$

$g = G_m/G_p$

$$G = \frac{E}{2(1+\mu)}$$

$$K = \begin{cases} = 1 & \text{for true-to-scale model} \\ = t_2/t_1 & t_1 = \lambda t_p \end{cases}$$

t_2 = increased thickness

TABLE 2 - Scaling Relationships for the SL-7 Structural Models

Measured Quantity	Steel Model	Rigid Vinyl Model
Length	L_s	$L_R = 0.5\ L_s$
Strain	ε_s	$\varepsilon_R = \varepsilon_s$
Stress	σ_s	$\sigma_R = 0.0167\ \sigma_s$
Force	F_s	$F_R = 0.00417\ F_s$
Moment	M_s	$M_R = 0.00208\ M_s$
Moment of Inertia	I_s	$I_R = 0.0625\ I_s$
Section Modulus	S_s	$S_R = 0.125\ S_s$
Polar Moment of Inertia	J_s	$J_R = 0.0625\ J_s$
Torque	T_s	$T_R = 0.00208\ T_s$
Shear	τ_s	$\tau_R = 0.0167\ \tau_s$
Unit Angle of Twist	θ_s	$\theta_R = 2.0\ \theta_s$
Total Angle of Twist	ϕ_s	$\phi_R = \phi_s$
Axial Deformation	δ_s	$\delta_R = 0.5\,\delta_s$

Note: In the above relationships,

$\lambda = L_R/L_S = 0.5$

$e = E_R/E_S = 0.0167$

$g = G_R/G_S = 0.0167$

$$G = \frac{E}{2(1+\mu)}$$

$$K = \begin{cases} = 1 \text{ for true-to-scale model} \\ = t_2/t_1 \quad t_1 = \lambda\, t_s \\ \qquad\quad\;\; t_2 = \text{increased thickness} \end{cases}$$

$K = 1.0$

TABLE 3 - SL-7 Rigid Vinyl Model Experiments

#	Experiment	Purpose
1	Hogging	Comparison of SL-7 steel model stresses
2	Sagging	
3	Midship Shear	
4	Positive Torsion	
5	Negative Torsion	
6	Torsion - Angle of Twist	Comparison of SL-7 steel model angel of twist measurements
7	High Torsion-Supported Ends	Comparison of stresses and angle of twist under high load for supported and freely hung model
8	High Torsion-Freely Hung	

Table 4 - SL-7 Model Loads

Steel Model load = 240 x Rigid Vinyl Model load

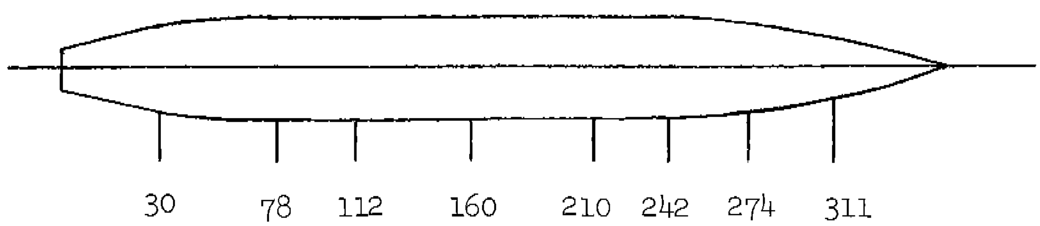
Prototype equivalent load = 598800 x Rigid Vinyl Model load (see Appendix A)

All weights in pounds

Experiment	Frame	Steel Model Load	Rigid Vinyl Model Load
Hogging	160 210	+3403 +3394	+14.18 +14.14
Sagging	160 210	-1667 -1912	- 6.95 - 7.97
Midship Shear	78 112 160 210 242 274 311	-1100 -1100 -2200 +2200 + 850 + 850 + 100	- 4.58 - 4.58 - 9.17 + 9.17 + 3.54 + 3.54 + 0.42
Positive Torsion* + Up starboard down port - Down starboard up port	30 78 112 160 210 242 274 311	+ 69.64 +550.0** +550.0** +550.0** -550.0** -425.0 -425.0 -280.36	+ 0.29 + 2.21** + 2.21** + 2.21** - 2.21** - 1.77 - 1.77 - 1.17

*Values of loads indicate magnitudes applied on either side of model, i.e. at Frame 30 the rigid vinyl model was loaded with 0.29# up starboard, and 0.29# down port. The distance between load points was 28" throughout the rigid vinyl model.

**Adjustment was required to correct for loading arm differences in the steel model.



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The direct comparison of a rigid vinyl structural model with its steel counterpart under equivalent load conditions has been a prerequisite to the final verification of the rigid vinyl modeling technique. Such a program was completed and the resulting correlation described herein indicates that the structural response of a rigid vinyl model can be used to

predict prototype characteristics effectively.

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