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THE USE OF SCANS FOR IMPACT STUDIES OF TRANSPORTATION PACKAGES

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THE USE OF SCANS FOR IMPACT STUDIES OF TRANSPORTATION PACKAGES

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ABSTRACT

This paper presents the results of an impact study using the computer program SCANS (Shipping Cask ANalysis System), which was developed by Lawrence Livermore National Laboratory (LLNL) for the U.S. Nuclear Regulatory Commission (NRC) and the Department of Energy (DOE) for structural analysis of transportation packages of radioactive materials. The program operates on IBM PC and compatible microcomputers. It has capabilities for other analyses such as heat transfer, pressure and thermal stress analyses. However, this study uses only the impact analysis capability, which includes a quasi-static and a dynamic analysis option. It is shown that the program produces reasonable results for a wide range of impact conditions. The results are in agreement with existing information on impact analysis and phenomenon. In view of its simplicity in modelling and convenience in usage, the SCANS program can be effectively used for confirmatory analysis, preliminary design study, and quick assessment of the need for detailed impact analysis.

INTRODUCTION

Federal regulations concerning the safe transport of radioactive materials specify that the capability of the packages for this purpose must be demonstrated (Reference 1). Under a specified set of normal and accident conditions of transportation, these packages must be able to meet certain radiological and nuclear standards. Although these requirements are not explicitly tied to parameters measuring the structural and mechanical integrity of the system, it is common knowledge that this integrity is essential for the packages to meet those standards. Thus the demonstration of structural integrity of a transport package is a critical part of the license and certification process for many of these packages. NRC Regulatory Guides 7.6, 7.8, and 7.9 give explicit guidance for the structural evaluation and analysis of spent fuel shipping casks. For this purpose, the specified sets of normal and accident conditions of transport are interpreted as the structural and mechanical load conditions. Among these load conditions, the drop or impact conditions present the most challenge to structural analysts and designers, mainly because the impact phenomenon is a complex one involving both the stiffness and mass of the structure and the linear and nonlinear behaviors of the materials. One of the popular and traditional methods for packaging design analysis is the quasi-static stress analysis method. This method assumes that the package behaves like a rigid body during an impact. Thus the effects of stiffness and vibrations are ignored. This simplified assumption of the method is often subject to criticism and more involved computer methods considering the above-mentioned effects are demanded. However, unfortunately, many modern computer programs for impact studies are either too limited for general design application or too complex for casual users. Moreover, a few only operate on super-computers and thus are not accessible to many people.

In view of this situation with computational tools for impact analysis, the SCANS computer program was designed to meet this need for impact analysis of transportation packages. The program runs on IBM PC and compatible microcomputer, so it is inexpensive and readily available. It provides both quasi-static and dynamic analyses and outputs rigid-body accelerations and other quantities useful to package designers. In addition, it uses simplified but adequate models in order to save computer time. For the impact, the program models the package as an elastic beam and the impact limiters as forces that change with the limiter deformation. For the period between two impacts, the cask is described as a rigid body and a rigid body kinematic solution is obtained. To further enhance the capability, the computer program is menu driven and user friendly; only a minimum amount of instruction and input is required to construct the model and execute the program. The study presented herein is to exercise this program's quasi-static and dynamic analysis capabilities for the oblique impact of a rail cask. The cask is assumed to have impact limiters of various stiffnesses. The computer results show that as the stiffness increases, the cask behavior changes from that of a rigid body to a vibrating body and eventually to a wave guide. Accompanying this expected change of behavior of the cask, the quasi-static solution is shown to change from being nearly identical to the dynamic solution to being about one-half of and finally to being much lower than the dynamic solution. This change of the ratio of the dynamic to quasi-static solution of SCANS is shown to be in agreement with the well known information in the literature on dynamic amplification factors for the quasi-static analysis method. This confirmation provides some support to the validity of the SCANS computer program.

This paper also reports some preliminary results from SCANS' lead slump analysis capability. Although the lead slump methodology of SCANS is highly simplified, it produces results very similar to those of the much more sophisticated nonlinear finite element computer code NIKE of LLNL. The reasons for this favorable comparison of results are explained in this paper.

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OBLIQUE IMPACT OF RAIL CASK

Figure 1 depicts the geometry of the rail cask analyzed. The cask is dropped from a height of 30 ft measured from the bottom limiter to the rigid ground. The cask strikes the ground at an angle of 45 degree measured from the horizontal ground surface to the cask axis. The SCANS program was used to produce quasi-static and dynamic results for four cases with different limiter stiffnesses. The force deflection relation of the cask limiters is linear and has a slope equal to the stiffness values given in Table I. The unloading slope of the limiters is five times of the loading slope. The limiters are identified as "soft", "firm", "stiff", and "rigid" to indicate their relative stiffness. The limiters are fictitious, although the value of the stiffness of the stiff limiter is equivalent to a 7" thick steel plate having the same impact area as the cask. The objective of this study with the wide range of stiffness values is to observe the change in the cask response as obtained by the SCANS computer program.

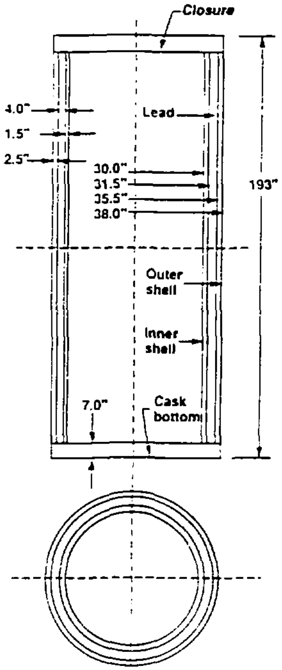


Figure 1. Dimensions of a typical rail lead cask

Figure 2a is an animation produced by SCANS for the impact of the soft cask. Each straight line represents the position of the cask axis at a given time, and the times are separated by equal time intervals. Thus more closely-spaced lines indicate slower movement of the cask. The positions of the cask near the end of the primary (first) and the secondary (second) impacts can be identified in the figure. The horizontal line at 0 ordinate represents the ground level.

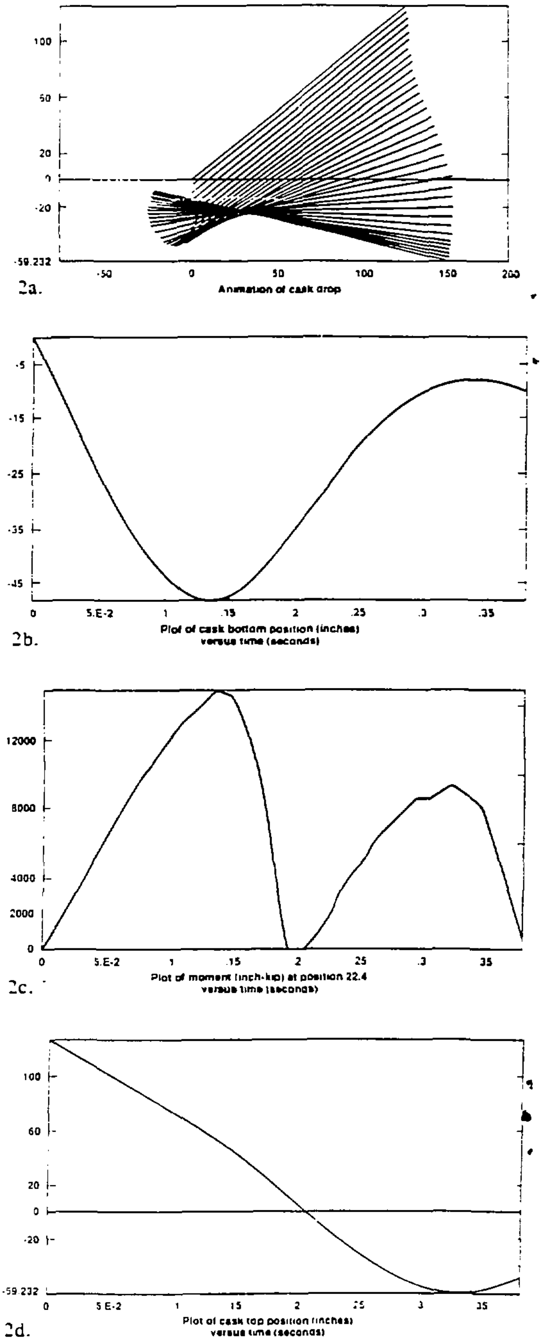
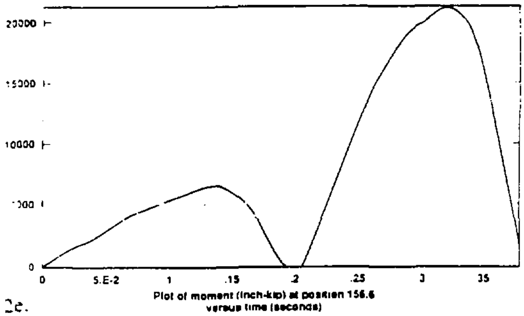


Figure 2. Sample results for a cask with soft impact limiters

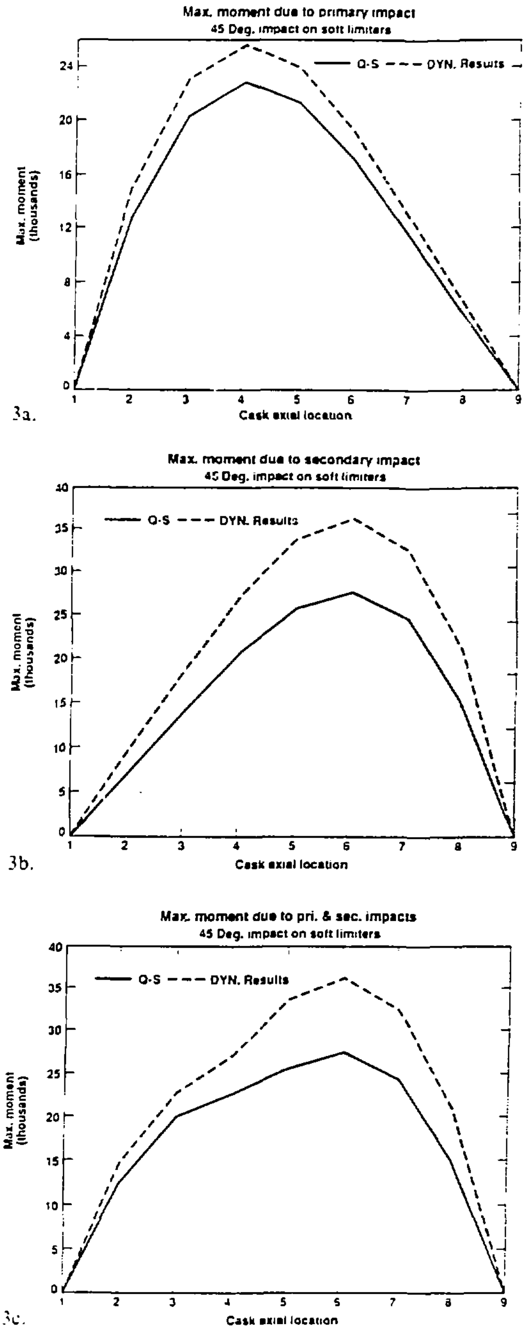


2e.

Figure 2. Sample results for a cask with soft impact limiters

The primary impact begins when the cask bottom reaches the ground level and the secondary impact occurs when the cask top falls to the ground. The distance from the ground to the impacting end below the ground is the total deformation of the limiter. The large maximum deformations of the limiters (up to 59.23") are the result of the softness of the limiters. It can be seen in Figure 2a that the bottom end hits the ground first and the other end hits after the bottom rebounds. The time separation of the two impacts can be clearly seen in the time histories results shown in Figures 2c and 2e. During this transition period, the cask is in free flight, and the SCANS program saves computer time by using formulas of rigid body kinematics for the displacement, and the force results are not obtained. The time histories given in Figures 2c and 2e for the bending moments in the cask show two separated pulses, corresponding to the two impacts. The duration of each pulse is the impact duration. The impact durations for this case are very long compared to the time required for the stress wave to traverse the length of the cask. No time delays or wave effects are apparent among the time histories of results obtained for different locations along the cask axis. All parts of the cask appear to move in phase as in a rigid body. Thus, for this case, the quasi-static and dynamic results are nearly identical. Figure 3 shows the comparison of the quasi-static and dynamic results for the maximum moment at all locations along the cask axis. However, these figures show that the dynamic results are higher than the quasi-static results, because the quasi-static solution in SCANS does not include the deformation of the limiter in the impact energy but the dynamic solution does. To correct this difference, a factor of (h+d)/h, where h is the impact height and d is the maximum limiter deformation, can be used to multiply the quasi-static results. It can be shown that the adjusted quasi-static results are nearly identical to the dynamic results. Accordingly, the quasi-static solution is adequate for long duration impacts as expected.

The dynamic time-history results for the stiff-limiter case are presented in Figures 4. Contrary to the soft-limiter case, the impact duration for the stiff case is very short and of the same order of magnitude as the time required for the stress wave to travel between the two cask ends. The propagation of stress wave becomes obvious when the time histories of the moments at two cask locations are compared. In fact, the rebound of the cask bottom appears to coincide with the return of the stress wave front to the cask bottom. Thus the impact force in the cask can not be built up by multiple wave reflections, and the maximum impact force is approximately equal to the single stress-wave force, which can be predicted using the well-known stress wave formula



3a.

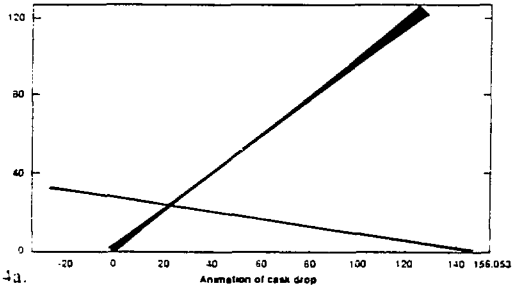
3b.

3c.

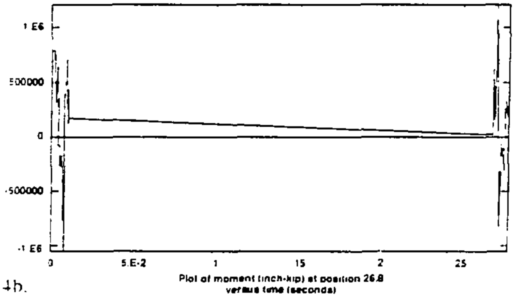
Figure 3. Quasi-static analysis is usually adequate for long duration impact

for a slender rod, i.e., F=Aρcv, where A is the cross sectional area of the cylindrical, lead-steel composite body of the cask, ρ is the mass density of the composite body, c is the compressional wave speed in the composite and v is the impact velocity. A review of the maximum moments in Table I reveals that the maximum impact force is also limited to about the same magnitude in the rigid-limiter case as in this stiff-limiter case. Thus for cases with very stiff impact limiters, the quasi-static analysis will over predict the impact results. This fact is demonstrated in Figures 5 which compare the maximum moments from the quasi-static and dynamic analyses.

The ratio of the maximum dynamic to quasi-static moment listed in Table I is equivalent the dynamic amplification factor which is often used with the quasi-static analysis to correct its deficiency due to the omission of stiffness effects. The amplification factor values in Table I are compared in Figure 6 to a prediction found in the literature for an impact with a half-sine-wave time history of the impact force (Reference 2). The comparison the two set of results is quite good. Both sets of data indicate that the case of the firm limiter has a much higher dynamic than quasi-static moment. An examination of the SCANS dynamic solution for this case reveals that the time history of the moment is much affected by the longitudinal vibration of the cask body, which produces multiple peaks in the time history. The vibration amplifies the dynamic solution to be higher than the quasi-static solution.



4a.



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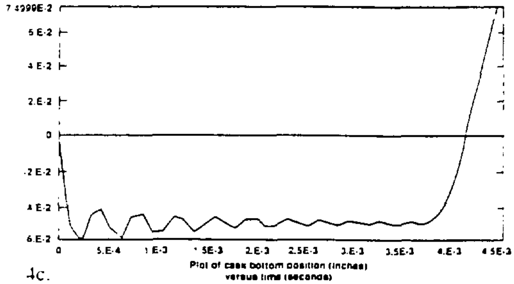

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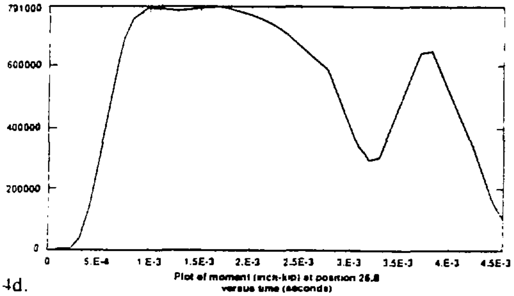

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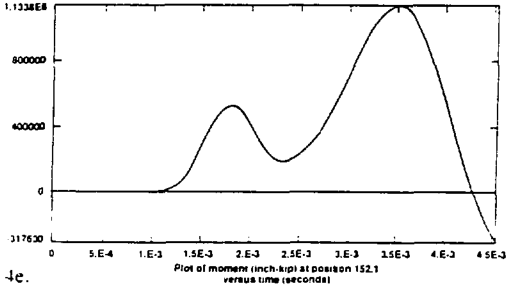


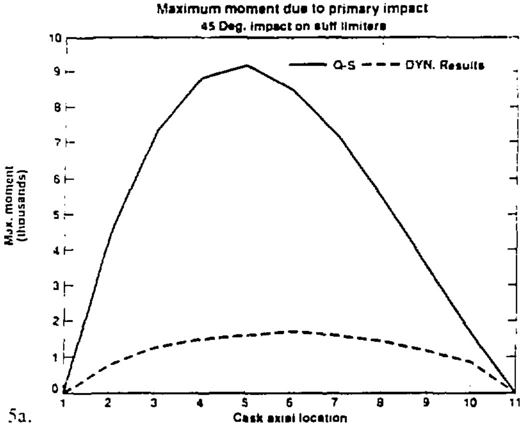
4e.

Figure 4. Sample results for a cask with stiff impact limiters

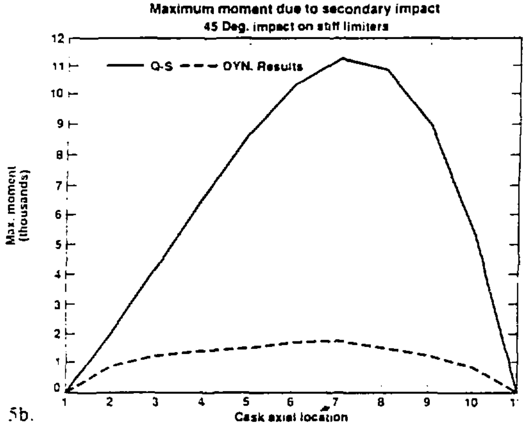
Table I.

Table I—30 ft., 45 Deg. Impact of Rail Cask
(Natural period approximately = .024 sec)

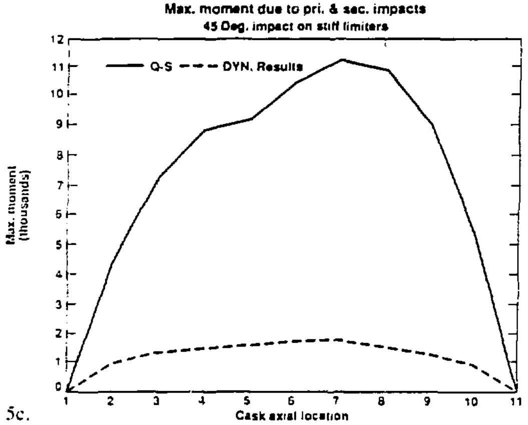
Impact Limiter	Limiter Stiffness (kip/in)	Max. Moment at Mid Span Q-S (in-kip)	Dynamic (in-kip)	Ratio Dyn/Q-S	Sec. Impact Duration (sec)
Soft	33	25943	33803	1.30	0.142
Firm	3333	269665	540000	2.00	0.015
Stiff	1500000	10444080	1762800	0.17	0.005
Rigid	3.3E+08	85275563	1720000	0.02	0.005



5a.



5b.



5c.

Figure 5. Quasi-static analysis can over-predict results for cases with stiff impact limiters

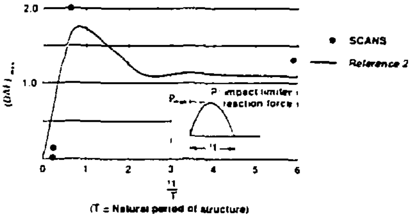


Figure 6. SCANS can provide the dynamic amplification factor that is essential for the application of quasi-static analysis

LEAD SLUMP ANALYSIS

SCANS has a simplified method for the evaluation of lead slump and its effects on the stresses in the steel shells. "Lead slump" or the permanent deformation of the lead shield of a cask sometimes occurs, if the lead is not bonded to the steel shells which encase the lead. Without the help of the bond and the steel shells, the lead shield has to bear the impact force alone and will produce large axial deformation, and a large lateral pressure will be exerted on the inner and outer shells as shown in Figure 7. This lateral pressure is detrimental to the shells' capability to resist axial buckling. Accordingly, this effect of lead slump should be assessed.

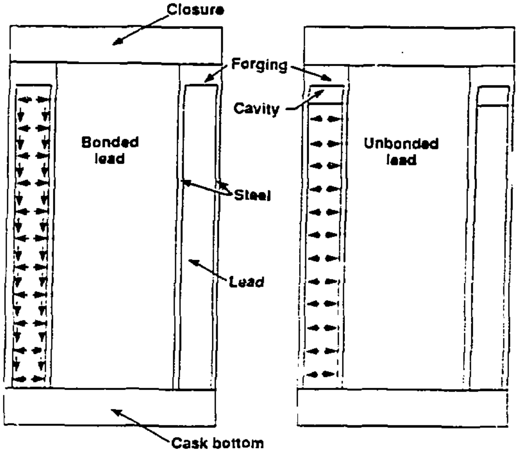


Figure 7. The cause and effect of lead slump

SCANS provides a simplified model for this assessment. The model assumes that the lateral expansion of the lead will cause a tensile and a compressive circumferential stress in the outer and inner shells, respectively. This circumferential stress in turn changes the axial stress of each shell through the shell material's Poisson effect. In the dynamic solution of SCANS, the lead and the shells are treated as two separate structures, and their axial forces are coupled through the Poisson effects. The lead slump or the permanent deformation of the lead is estimated by assuming that the deviatoric elastic stress energy is totally converted to the plastic deformation energy of the lead. The hydrostatic component of the axial stress, which can be quite high in the confined lead, will not produce any plastic deformation.

Table II shows the lead slump and stresses as predicted by NIKE and SCANS for a 30 ft. drop of the rail cask with a nonlinear impact limiter. NIKE is a sophisticated finite element computer program with elastic and plastic capabilities. Two NIKE solutions are shown therein. The elastic solution assumes a Young's elastic modulus of 25000 psi for the lead, while the plastic solution uses the same value as the plastic modulus. In addition, the plastic solution assumes a Young's modulus of 2.0E6 psi and a yield stress of 250 psi. Despite the great difference in the material models of the two NIKE analyses, the two sets of stress results do not appear to be drastically different. The SCANS result also appear to be close to the NIKE results. This comparison seems to suggest the following: (1) The stress results are mainly determined by the plastic modulus of the lead; (2) the lead slump depends largely on the yield stress of the lead; and (3) the plastic problem can be effectively solved as an elastic one using the plastic modulus as the elastic modulus. These observations are probably due to the fact that the impact is a monotonically increasing load and the plastic solution will not differ from the elastic solution until unloading occurs.

Table II.

Table II—30 ft. End-on Impact of Rail Cask

	Max. Stress in Lead (PSI)			Max. Stress in Inner Shell (PSI)		Max. Stress in Outer Shell (PSI)		Max. Lead Slump(in)
	Radial	Circumf	Axial	Circumf	Axial	Circumf	Axial	
NIKE								(Note 1)
Plastic	-1900	-2380	-2850	-29625	-9900	18995	-235	1.25
Elastic	-1189	-1488	-2250	-26025	-7523	17950	-1325	
SCANS	-1444	-1750	-2508	-31245	-7548	22433	238	1.42

Note 1: The Lead slump values are obtained for a low lead yield stress of 250 PSI. There will be no lead slump for yield stress of 2500 PSI

CONCLUSIONS

The results of this study indicate that the SCANS computer program can be used to perform design study and obtain necessary understanding of the impact phenomenon for design improvement.

ACKNOWLEDGEMENTS

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