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Management of Dry Flue Gas Desulfurization By-Products in Underground Mines

The Development and Testing of Collapsible Intermodal Containers for the Handling and Transport of Coal Combustion Residues

Topical Report

Jeffrey L. Carpenter
Edwin M. Thomasson

July 1995

Work Performed Under Contract No.: DE-FC21-93MC30252

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Southern Illinois University
Carbondale, Illinois

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THE DEVELOPMENT AND TESTING OF COLLAPSIBLE INTERMODAL CONTAINERS FOR THE HANDLING AND TRANSPORT OF COAL COMBUSTION RESIDUES

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ABSTRACT

SEEC, Incorporated, is developing a collapsible intermodal container (CIC™) designed for containment and transport of fly ash and other dry-flowable bulk commodities. The CIC is specially configured to ride in open top rail cars, but as an intermodal container, it also rides in barges and on flat bed trailers. This allows SEEC to use unit coal train back haul capacity to transport fly ash to markets at and near coal mines.

SEEC's goals for this project were to design a CIC for handling and transporting dry fly ash, and then demonstrate the CIC technology. During this project, SEEC has performed extensive initial design work, leading to the manufacture of three prototype CICs for demonstration. Preliminary tests to examine safety issues included finite element analyses and an overload test in which the CIC was lifted while carrying weight in excess of its rated capacity. In both cases, the CIC met all safety requirements.

With the above information satisfying possible safety concerns in hand, SEEC worked with SIU and other cooperators to plan and carry out field demonstration and testing of three CICs. This demonstration/testing including filling the CICs with fly ash, transporting them in a coal hopper car, handling with standard intermodal equipment, and emptying by inverting (two CICs) and by vacuuming (one CIC). Results were very positive. Filling with fly ash, transporting, and intermodal handling went very well, as did emptying by vacuum. Emptying by inverting was less successful, but most of the problems were predicted ahead of time, and were mostly due to lack of fly ash fluidizing equipment as much as anything. Throughout the testing, valuable information was gathered that will greatly accelerate refinement of both the CIC and the system of CIC handling.

BACKGROUND

Generation and Use of Fly Ash in the U.S.

As coal is burned in electric power generating plants, several types of combustion residues are formed. These may be classified as (1) fly ash; (2) bottom ash; (3) boiler slag; and (4) flue gas desulfurization (FGD) or "scrubber" sludge. Each of these coal combustion residues has its own characteristics and, in some cases, its own commercial uses.

Fly ash is recovered from the stack gases, usually by electrostatic precipitation processes. It is a very fine residue, in appearance somewhat like talcum powder. It is sometimes used in concrete mixes, in soil rehabilitation, and in acid neutralization. Because the fly ash particles are so fine, they create fugitive dust problems when being handled and transported.

Bottom ash is recovered, as the name implies, from the bottom of the coal fire beds. It is often in large chunks, but can be ground to various degrees of fineness. Its most frequent use is for granules in roofing shingles.

Boiler slag is similar to bottom ash, the difference being in the type of combustion used in the burning of the coal. Commercial uses are similar to bottom ash.

FGD scrubber sludge is recovered from scrubbers, which are devices installed to remove sulfur oxides from stack gases. These scrubbers usually spray a mixture of finely ground limestone (or lime) and water into the stack, where the sulfur compounds react and are precipitated. The resulting product is gypsum or gypsum-like material. Commercial uses include the manufacture of wallboard and other gypsum products.

Table 1 shows the production and utilization of coal combustion residues in the United States in 1991. The general trend of such products and utilization has not changed significantly since then. Table 2 shows the estimated coal combustion residues that will

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Type of Residue	Production (M) Tons	Percent Used	M Tons Used
Fly Ash	51.3	25.7	13.2
Bottom Ash	13.3	37.6	5.0
Boiler Slag	6.5	55.4	3.6
FGD Sludge	18.1	1.9	0.34

Table 1. U.S. Coal Combustion Residues Production and Utilization, 1991.

Type of Residue	Estimated Production (M Tons)	Percentage Increase Over 1991
Fly Ash	64.1	25
Bottom Ash	16.4	23
Boiler Slag	8.1	25
FGD Sludge	40.0	120

Table 2. Coal Combustion Residues Estimated Production in 2001.

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be produced in the year 2001. As can be seen, the production of fly ash, bottom ash, and boiler slag are expected to increase only about 25 percent over 1991 production. However, the production of FGD or scrubber sludge is expected to more than double over the 10 year period. This is due to the Clean Air Act, which dictates that coal burning electric power plants reduce their sulfur oxide emissions very significantly by the year 2000. It is believed that many such utility companies will install scrubber equipment in their coal burning plants, while others may elect to convert to the use of low sulfur coal.

Because of its physical characteristics, particularly the very fine particle size, fly ash is the most difficult coal combustion residue to handle and transport. Also, as can be seen from Tables 1 and 2, the amount of fly ash to be handled, transported, and either utilized or disposed of in an environmentally sound manner is quite large at this time, and will continue to increase in the future. It is for this reason that new technologies for handling, transporting, utilizing, or disposing of fly ash are important. The CIC technology developed by SEEC represents one method of coping with the problems presented by fly ash.

Problems Associated with Fly Ash Handling and Transport

When dealing with fly ash, one of the most difficult problems faced by the industry is handling and transporting the ash in a reliable and cost-effective manner that adequately protects human health and the environment. Two major problems are fugitive dust and the tendency of many ashes to harden when wet, which is potentially damaging to handling equipment.

Several approaches to fly ash handling and transport have been tried for various industrial applications:

> Mixing ash with water effectively suppresses dust, but it aggravates clean up problems, especially with ashes that harden. An additional problem is that adding water also adds weight, thereby increasing transportation costs.

Chemical polymer coating (or in some cases a water coating) to form a crust over dry ash that has been placed in empty open top rail cars has also been tried. This method suffers from fugitive dust problems until polymer is in place, requires a costly ash handling system to be constructed at the destination, and can leave residue of ash and polymer in rail cars, which then need to be cleaned. Finally, this method provides no protection from rain, snow, or contaminants en route.

Pelletization of fly ash, and transport of the pellets is another method that has been tried. Pelletization has met with very limited success due to technical and economic problems.

Pressure differential (PD) rail cars or trucks can be used. The key advantages of PD are that ash is fully contained during transport, and that the system is standardized and well accepted by the industry. However, PD is typically a high-cost solution that lacks versatility, so has found only limited applications. The high total cost is driven largely by high front haul transportation costs and the lack of back haul opportunities. In addition, once the PD car reaches its destination, the ash is often transferred directly into a secondary transport vehicle, or into an ash silo and then into another transport vehicle. Whenever additional ash handling steps such as these are needed, the cost increase can be dramatic. Finally, simple logistics of getting PD rail cars to where they are needed at the time they are needed can be very difficult, especially when the cars are competing for track space with coal trains.

Benefits of CIC Technology for Handling and Transporting Fly Ash

SEEC, Inc., has developed a system that provides many of the advantages found with pneumatic transport, but with greater versatility and often at a lower cost. The centerpiece of the SEEC System is the CIC, which the company's unique transportation and materials handling capabilities are built around. In essence, the CIC is a portable and collapsible storage bin that allows bulk commodities to be moved from place to place and between different types of vehicles by handling the container, not the contents. The CIC is specially configured to ride in empty coal cars, and special care has been taken to ensure that adding CICs to a coal transport system will not disrupt the tight schedule of unit trains. But the CIC is truly intermodal, and may also be carried in river barges, on flat bed trailers, and stacked in cargo holds of ships. CICs allow customers to take advantage of a basic tenet of the intermodal industry -- it is easier and cheaper to move a container full of material that to move material between containers.

Transport of dry-flowable materials in CICs reduces product handling, particularly at transfer points between different types of transportation (e.g. transfer from rail to truck). CIC's virtually eliminate fugitive dust problems during filling, emptying, storage, and during transport. Watertight and airtight, the CIC completely encloses its contents, keeping them clean and dry in all types of weather. CICs also protect against spillage, providing a liner that keeps ash from "contaminating" the rail cars, thus avoiding the expense and delay of cleaning the cars. CIC handling has been designed around standard industry equipment so that CICs can be easily plugged in to existing operations. Finally, the CIC collapses down to a small bundle for ease of storage and transport when empty. The net result is the first container that can effectively use unit coal train back haul capacity to safely and economically transport coal combustion by-products and other hard-to-handle materials.

Innovative Mine Reclamation System Based on Beneficial Use of Residuals

SEEC's System expands opportunities to use fly ash and other by-products to enhance mine reclamation and improve the environment while meeting regulatory requirements and reducing long-term disposal costs for utilities. Alkaline fly ashes, for example, can help treat and prevent acid mine drainage. Fly ash can also be a valuable soil amendment due its effects on soil pH, its contribution of soil bulk where topsoil is lacking, and in some cases its addition of certain micronutrients to the soil. These and other benefits may create opportunities to use fly ash to improve reclamation. Similarly, FGD scrubber sludges and other coal combustion by-products offer great potential if transport and handling problems can be overcome.

While coal combustion residues are valuable alone, their effects are multiplied when combined with compostable by-products like biosolids, compostable municipal solid waste, and others. These by-products can provide nutrients, increase water holding capacity, improve soil structure, and improve other soil attributes, which together greatly increase plant growth potential on reclaimed coal mines and other degraded lands. Instead of spending millions of dollars to bury these materials, SEEC's System creates an opportunity to save money while benefiting society and the environment.

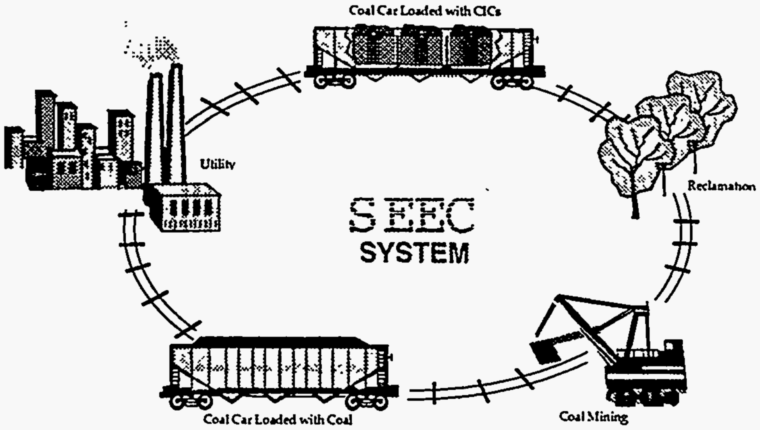
In summary, by virtue of its CIC-based transportation and handling technology, the SEEC System is uniquely able to bring together the pieces needed to put proven reclamation concepts into large-scale and commercially viable practice (Figure 1).

In addition to surface reclamation, the ability to cost-effectively transport large volumes of fly ash to coal mines opens opportunities for back-filling underground mines. This can help prevent subsidence and can also help prevent or correct acid mine drainage from underground mines.

CIC is the Centerpiece of a System to Expand Beneficial Use Markets

In addition to direct uses for fly ash at coal mines, CICs provide opportunities to expand markets for fly ash in concrete and other industrial uses. Typically, the geographic market limits are established by transportation costs. By using rail back haul to reduce transportation costs, it is possible to expand fly ash markets into to coal mining regions, thereby significantly increasing fly ash marketing opportunities for utilities.

Figure 1. Graphic illustration of how CICs allow use of unit coal train back haul capacity to transport large volumes of fly ash and other coal combustion by-products for beneficial use at coal mines and in nearby markets.



GOALS AND SPECIFIC OBJECTIVES

The goal of this project was to develop and demonstrate the CIC concept for fly ash handling and transport. Specific objectives toward meeting this goal were as follows:

1. Develop the CIC as a fly ash handling and transport system. This includes design of the CIC itself, design of the CIC handling and transport system, and initial testing.
2. Field demonstrate the CIC as a fly ash handling and transport system, including: the general approach to dust-free filling and emptying; the CIC's capabilities for ash containment while staged, handled, and during transport; and the CIC's capabilities for intermodal transport in triple hopper cars and on flatbed trailers.
3. Assess economics of various handling/transport systems.
4. Develop a health and safety manual for safe operations using CICs.

DESCRIPTION AND EVALUATION OF CIC TECHNOLOGY

Develop Fly Ash Handling/Transport System

Studies Related to CIC Design

Conceptual Design

SEEC was originally planning to use a collapsible container that could be provided by Amfuel Corporation. SEEC conducted a feasibility test using these containers, beginning in the fall of 1993 and concluding in January of 1994. The results of this test showed that SEEC's system was viable, but also demonstrated several serious shortcomings of Amfuel's container for this application. Key problems from SEEC's perspective were the container's small size (not enough capacity for economical transport), small fill/empty ports, and concerns about its strength, durability, and stability during transport and handling. Railroads also expressed concerns about carrying a container that does not fit well in their cars. Because of these issues, SEEC began working with several partners to design and manufacture the CIC container. Though this design work was not an anticipated requirement when the cooperative agreement was being developed, it has turned out to be an excellent opportunity for SEEC to approach the design with a clean slate and develop a container that is optimized for rail back haul.

The materials handling and transport system built around the CIC has been designed to be as simple and reliable as possible. SEEC's approach has been to create a CIC design that can fit smoothly into existing operations with only a bare minimum of specialized equipment. A key advantage is that SEEC's system is designed to handle the container instead of the contents. Thus, the CIC serves many roles, including storage silo, rail car liner, and intermodal container. Because of the many variables that must be factored into CIC design, SEEC has worked closely with experts in several key industries (rail, crane, and fabric container manufacturing, etc.) during the design process.

Accomplishments during the first year of this project included completion of conceptual CIC design (Figure 2), small scale testing using a model CIC and model rail car hopper, and the manufacture of three prototype CICs for testing and demonstration (Figure 3).

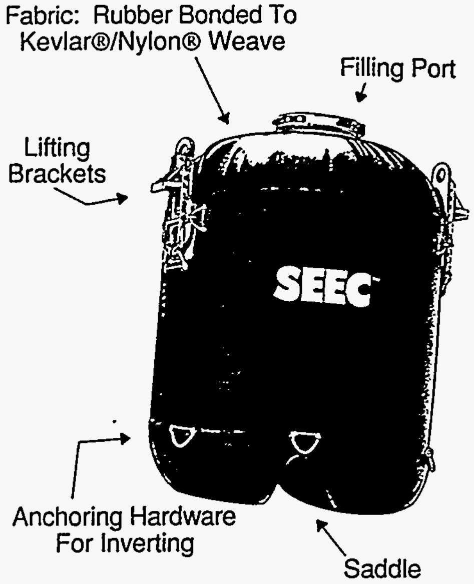


Figure 2. Representation of a filled prototype CIC. Key components include: the CIC fabric; the top filling port, which in the configuration shown is also used for emptying; lifting brackets, which position the brackets on rail car top chords and support weight during rail transport; anchoring hardware; and a saddle for aligning with the center sill of certain coal cars. The prototype CICs used for testing were manufactured using separate layers of Kevlar® and nylon instead of a single woven layer, and the top port was off-center.

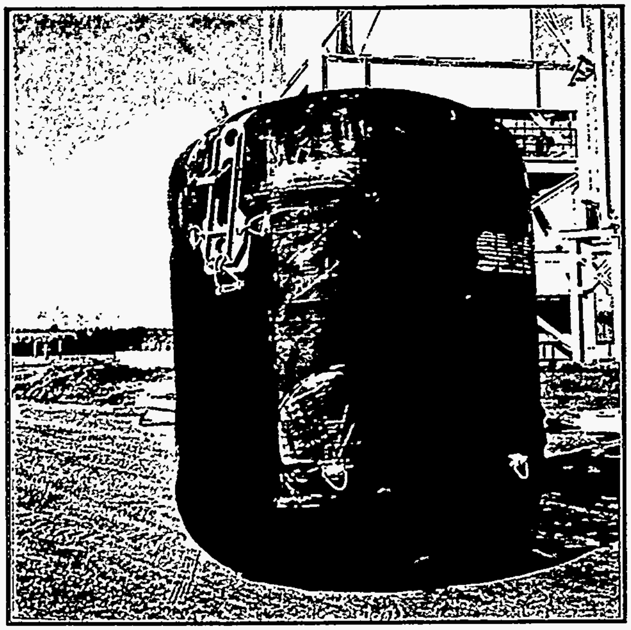


Figure 3. One of three prototype CICs manufactured for pre-commercial testing, and for use in the demonstration of CIC capabilities as part of this cooperative agreement.

Extensive testing of the three prototypes (described below) led to design enhancements which are being incorporated into a second generation CIC. This has resulted in a nearly commercial-ready product. One or more of these second generation CICs will be manufactured and extensively tested, so that additional enhancements and modifications can be identified and incorporated into the commercial product.

The second-generation CIC(s) will be manufactured from an ultra-violet resistant rubber compound bonded to a fabric comprised of nylon interwoven with either aramid or kevlar® (the fabric used in bullet-proof vests). This combination produces a CIC skin that is extremely strong and durable, with a projected 10-year life span under continuous use. This weave will also reduce the thickness of the CIC sidewalls, making them more flexible than the first-generation prototypes, and allowing the container to be collapsed to 5% to 10% of its filled size when empty. Additional modifications have been made to improve collapsing and to improve filling, emptying and general handling. The second generation CIC remains approximately ten feet tall and nine feet in diameter, providing a capacity of up to 22 cubic yards and 20-30 tons depending on the bulk density of the product. More detailed specifications of the CIC are presented in Table 3.

CAPACITY*				DIMENSIONS WHEN FILLED		
Cubic feet	610	Liters	17,270		Inches	Meters
Gallons	4560	Bushels	490	Diameter	106	2.69
Cubic Yards	22.6	Cubic Meters	17.2	Height	120	3.05

GENERAL OPERATING INFORMATION*			
Filled Weight	20-28 tons		Operating Temperature
(65-90 lb/cu ft)	18-25 metric tons		Maximum +140° F (+60°C)
Empty Weight	600 lbs. (272 kg)		Minimum -20°F (-29°C)

Table 3. Specifications of the CIC 610

Finite Element Analysis

SEEC contracted with Sims Professional Engineers, a rail car engineering firm, to perform computer-aided finite element analysis. This analysis involved simulation of stresses occurring in four specific cases, using a base load of 20 tons per CIC:

1. Stresses on filled CICs when lifted.
2. Effects on CICs during transport.
3. Effects on triple hopper cars during transport.
4. Effects of repeated impact.

Results of these analyses indicate that in no cases will transporting CICs in a rail car compromise the integrity of either the CIC or the rail car, and all elements of the CICs and rail car are within Association of American Railroads (AAR) limits. A copy of the complete analysis is included as an appendix.

Overload Test

The first CIC that was manufactured was subjected to an "overload test." As suggested by its name, this test consisted of filling the CIC above its rated capacity, lifting the CIC using an overhead crane, and looking for signs of undue stress. In addition, this test provided the opportunity to test the CIC's behavior during emptying by inverting, though in this case the material handled was wet sand.

Results of this test indicated that CIC integrity was not compromised when subjected to weight that exceeded it's rated capacity. This test was performed at the request of, and in cooperation with, the chief engineer of Engineered Fabrics Corporation (EFC), which is the manufacturing company. EFC was satisfied with the overload test results, and gave approval for further tests using rated loads and no special precautions. It is worth noting that the CIC fabric is designed with a 12:1 safety allowance, and the supporting webbing has an 8:1 safety allowance designed in. This means that the fabric can theoretically hold twelve times its rated load of 20 tons, and the webbing eight times the rated load before failing.

Design Studies Related to CIC System

The key to effectively using CICs for ash handling and transport is to minimize labor and capital costs associated with filling, transport, emptying, and general handling. In other words, there is a need to create a system around the CIC which capitalizes on its inherent advantages without adding new problems.

SEEC has made conceptual system design a major focus of its work to date. In essence SEEC has worked through every step of the process for using CICs to transport fly ash. The current effort is to streamline the system so that every process is simple, efficient, and low cost. At almost every step, SEEC has identified standard equipment that can be used as is, after scale-up, or after scale-down, to economically incorporate a CIC-based system into ongoing operations fly ash handling operations.

Field Demonstrate Concept of CICs for Fly Ash Handling and Transport

SEEC's objective was to demonstrate the capability of its CICs to perform in a rail back haul system, but also to treat this demonstration as a testing opportunity from which to learn as much about handling performance as possible. Results could then be very useful for refining the CIC design and optimizing the CIC handling system. This demonstration included filling of CICs with fly ash, transporting the filled CICs in a triple hopper car, and emptying the fly ash by inverting the CICs and by vacuuming.

Filling CICs

The field demonstration of filling CICs with fly ash was conducted at the Illinois Power Company's Baldwin Power station on November 17, 1994. Baldwin has an ash silo fitted with a standard ash dispensing spout that accordion's up and down, and is designed to fill PD ash trucks.

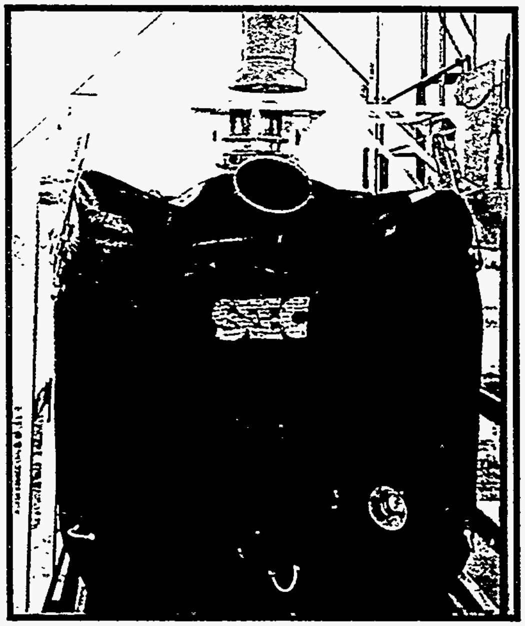
This demonstration was performed using low-cost and low-technology methods that demonstrated the system concept, but required much more labor that a commercial system would. SEEC provided a "filling station," consisting of a support structure that supported the CICs during filling, and a removable interface that provided a dust-free connection between the ash spout and the CIC. This filling station had a catwalk to provide physical access to the interface and the CIC port. In operation, the CIC port was clamped to the lower side of the interface, and the fly ash spout was lowered onto the interface's top plate for filling.

To avoid disrupting other activities at the Baldwin station, the filling station was carried on a flat bed trailer as an entirely self-contained unit. CICs were placed into the filling station and connected to the interface, then the entire unit was moved into position under the ash spout (Figure 4). When the filling station was placed into position, the ash spout was lowered onto the interface, and the ash flow was initiated. Filling occurred at a rate of 3 to 3.5 tons per minute (as fast as the ash flowed out of the silo), and there was essentially no fugitive dust. The amount of ash discharged into the CICs ranged from 17 to 20 tons. The CIC that held 20 tons was entirely filled, and could not have held any more ash without allowing the ash to settle first.

Once filled, the ash did settle relatively quickly, and it is possible that accelerated settling could increase total capacity by 10-20% or more. For example, vibration of smaller bulk bags during filling is often used to increase the settling rate, thereby increasing capacity without slowing down the filling process.

Figure 4.

Filling station containing CIC positioned under ash silo and ready for filling.



Transporting CICs in Triple Hopper Car

Filled CICs were immediately transported on the flatbed trailer to a nearby rail siding where a CSX triple hopper car was waiting. The CICs were lifted out of the filling station and placed into the hopper car, with one CIC in each hopper bay (Figure 5). The crane used for this demonstration was a boom crane, with a spreader bar provided by the crane operator. The equipment was not designed for use with CICs, so did not give a good representation of real world labor and time requirements. Nevertheless, we did gain valuable experience related to properly positioning CICs so that the lifting bracket hooks rested on the hopper car's top chord, and so that each CIC was centered in its hopper (Figure 6). This process became more efficient with experience, so that by the time we loaded the third CIC (as part of the demonstration in front of guests), it only took about five minutes to attach the spreader bar, lift the CIC, and place it in position. This amount of handling time could be further reduced in an operating system, which would typically include a more CIC-friendly spreader bar and a more experienced operator.

Figure 5. Suspended CIC being lowered into the rail car. Two CICs that were loaded into the car earlier are visible in the background. Note the hooks that are designed to rest on the top chord to hold the lifting eyes in position for rapid and reliable lifting.

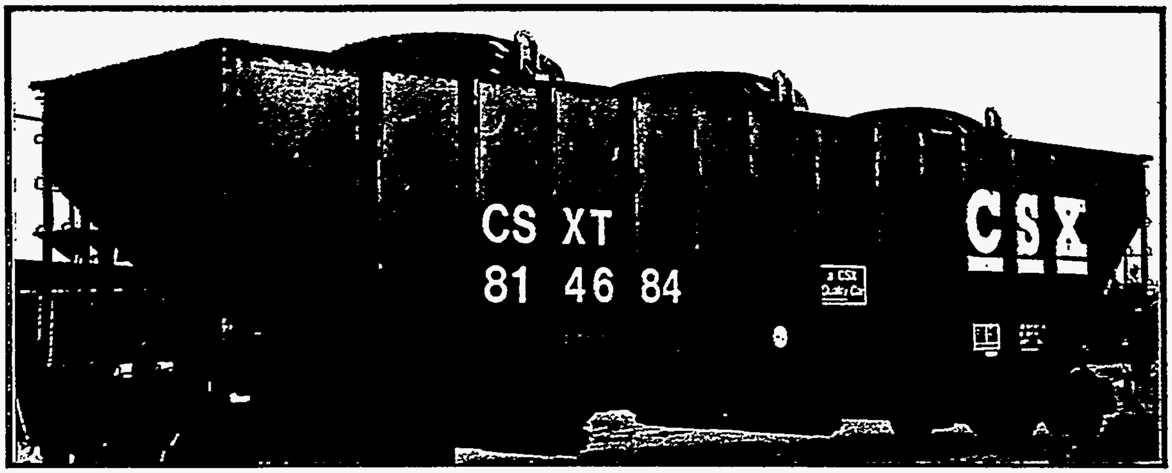


Figure 6. Side view of the triple-hopper car containing three CICs.

The three CICs were transported over 2000 miles in a round trip journey to Norfolk, Virginia, and back. In Norfolk, the CICs were taken to a pier that handles standard intermodal containers (rigid 8' x 8' x 20' or 8' x 8' x 40' containers). An overhead gantry crane (Figure 7) and an articulating gantry crane (which performs ship-to-shore container transfers) were used to move one CIC out of, and back into, the rail car. The CIC was also transported on a flatbed trailer within the pier yard to examine the stability of the free-standing container during transport (Figure 8). There were no problems encountered with any of these activities, and the container handling experts at the pier assured us that they could efficiently handle CICs in large numbers with little additional equipment.

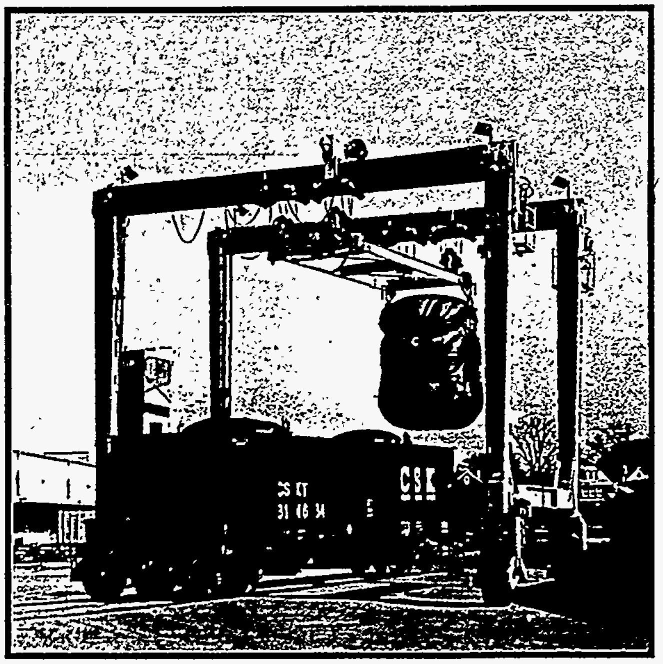


Figure 7. One CIC was lifted using a gantry crane at Norfolk Southern's Lambert's Point facility. This is one type of crane that can be used to rapidly remove CICs from rail cars so that the train can be filled with coal and sent back to the utility without delay.

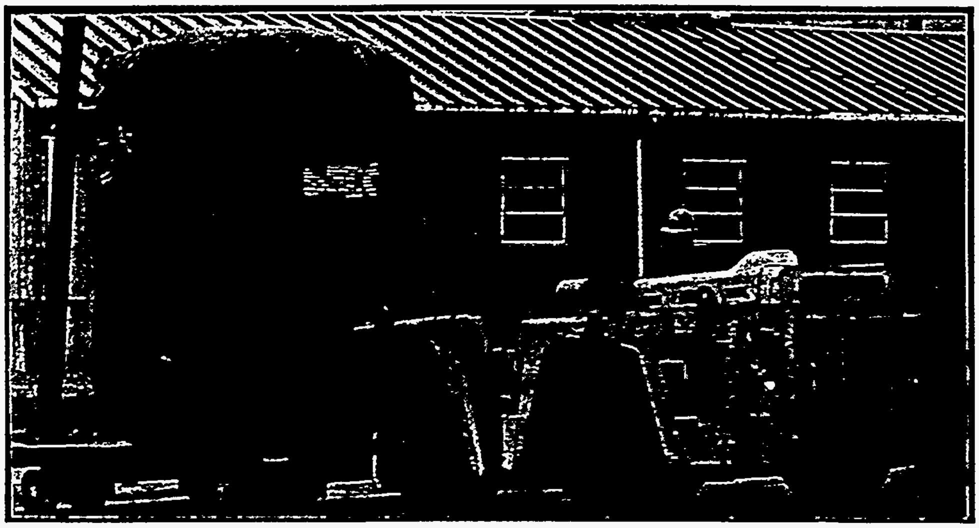


Figure 8. One filled CIC being transported by a tug and tote trailer at Norfolk Southern's Lambert's Point facility. The CIC was not anchored to the trailer at this time, yet remained very stable.

Test of CIC stability during transit

SEEC tapped the expertise of Sims' engineers to assess CIC stability during transport. Accelerometers were used for this analysis, one strapped to a CIC, the other strapped to the rail car's internal bracing. Accelerometers are designed to measure longitudinal, lateral, and vertical shock and vibration over time. In this case, they provided a record of shock and vibration experienced by the hopper car, and by one CIC in that car, during transport. A comparable test measuring shock and vibration of a hopper during a trip of 14,787 miles, was conducted by the Association of American Railroads. Sims used the AAR test as a baseline for comparison.

The longitudinal accelerations experienced by the hopper car carrying CICs were as high as 27.6 g's (27 times gravity). This is many times greater than the maximum longitudinal acceleration of 1.37 g's measured by the AAR during its test. In general, there were several accelerations experienced in the SEEC test above 2 g's that indicate it experienced a "rough ride" longitudinally. Vertical "bouncing" of the rail car was more in line with the AAR test than was the longitudinal data. Even so, in the 2 to 4 g category, the SEEC test was more severe because more "bumps" per mile were detected than in the AAR test. The accelerometer strapped to the CIC experienced significantly less vibration and shock than the accelerometer attached to internal bracing. This suggests that the CIC effectively absorbed much of force that was exerted upon it.

Sims' engineers concluded that "the CIC successfully withstood the severe environment without incident. The open top hopper cars also did not experience any distress by carrying these containers in this severe operating environment."

Emptying

CICs were emptied in two ways. Two CICs were inverted, and ash was emptied by pouring it from the top port. One CIC was emptied using industrial vacuum equipment. For inverting, the CICs were placed into a frame support, and the entire support was inverted (an example of inverting to empty wet sand is shown in Figure 11). This emptying took place at the Peabody Coal Company Marissa cleaning plant refuse disposal site near the Baldwin Power Plant. The ash had compacted so thoroughly during transport that it flowed very poorly. Because of the remote location, there was no access to fluidizing equipment, and so we had anticipated some difficulty with emptying in this manner. The highly compacted ash was found to flow very poorly, confirming our belief that gravity discharge through either a top or bottom port would require a reliable means to fluidize the fly ash.

The third CIC was emptied by vacuum. Vacuuming is commonly used to handle dry fly ash, cement, and similar materials in commercial operations. Vacuuming is also easier to test at a conceptual level than inverting because mobile equipment for industrial vacuuming is readily available. SEEC obtained the services of a commercial vacuum service that provided a truck-mounted industrial vacuum. Two key findings emerged. First, even though the fly ash had been compacted to the point where it represented a worst-case scenario, the vacuum had absolutely no problem removing that ash efficiently and in a timely manner. Second, the vacuum lines were easily adjusted to totally prevent fugitive dust emissions. Our results suggest that vacuuming could be a very reliable and economic method for emptying CICs. SEEC's investigations of vacuum systems suggest that a 20 minute turn-around per CIC is well within system capabilities, from both technical and economic standpoints.

Assess Economics of Fly Ash Handling/Transport Systems

SEEC has provided a general description of its ash handling and transport system to the SIU project team for their use in developing an economic model. This information has included general information about the economics of SEEC's system for initial model development. Because details of SEEC's system are still being refined, the assumptions for such a model are not yet fixed. Nevertheless, SIU has made excellent progress in developing a functional economic model, and SEEC will continue to work with SIU, providing the most up-to-date information possible.

SEEC has developed its own model for estimating system costs under specific commercial scenarios. SEEC's model allows customers to select among several system options, so produces cost estimates based on prospective customers site-specific objectives. SEEC has developed realistic cost estimates for essentially all components of its system, and each component can be included in or deleted from a given economic estimate. Several cost estimates have been run, and in almost all cases, SEEC's system has been cost-competitive with alternative systems..

Health and Safety Issues

SEEC's first priority for this project and any commercial system is the health and safety of everyone who works with and around CICs. Therefore, SEEC is developing a safety and training manual for working with and around CICs. Key issues include general safety precautions working around heavy and/or automated equipment, as well as safety issues related to possible exposure to CIC contents. SEEC's manual is subject to ongoing revision and updates as the system develops, but has been largely completed.

FUTURE PLANS

During the testing described here, SEEC carefully examined the performance of various CIC components with an eye toward maximizing reliability, cost-effectiveness, and usefulness to the industry. With this information, SEEC is moving rapidly to refine both the CIC design and the system built around it.

CIC design refinement

SEEC has identified several ways to increase the CICs value while reducing its manufacturing and handling costs. All design refinements were directed toward three keys to commercialization: reducing labor and capital costs; increasing overall system efficiency and reliability; and allowing automation where possible

General target areas and are as follows:

- Modify lifting brackets for greater accessibility and reliability.
- Streamline filling port for ease of access, opening, and closing.
- Streamline overall design, improving fabric, optimizing other hardware, and eliminating "saddle" and anchor patches to enhance collapsing and handling when empty.
- Make the CIC pressurizable for situations where that is desirable.

CIC System refinement

Refinement of the CIC handling and transport system is continually focused on improving versatility, reliability, cost-effectiveness, and the ability of CIC-based systems to meld smoothly with existing customer operations. SEEC will continue to identify and develop various options for filling and emptying CICs, and for handling the CICs when both full and empty. Upon completion of the refined CIC design, one or a few will be manufactured for further testing . These CICs will be used to test all system components, so as to optimize all aspects of fly ash (and other dry-flowable commodity) transport and handling.

CONCLUDING REMARKS

SEEC has successfully completed all of its responsibilities as set forth in the cooperative agreement, included design and preliminary testing of the CIC. Based on testing results, SEEC is very optimistic about the commercial viability of its system. SEEC, working closely with SIU and other cooperators, has proven the technical feasibility of transporting and handling fly ash and other dry flowable materials in CIC. In most respects, including dust-free filling, safe handling using standard equipment, and transport in a coal hopper car, the CIC performed better that might have been expected of a prototype container.

As with any development project certain problems were encountered particularly related to handling and emptying. Most of these problems were anticipated, and working through the testing allowed the precise targeting of improvements in CIC design and CIC handling. Thus, one further iteration of refinements to CIC design and to the system of filling, handling, and emptying, is projected to produce a commercially viable fly ash handling and transport system.

Economic estimates of the current system are very promising, and ongoing refinements will make the CIC system even more competitive. SEEC believes that its system will fill a unique niche in the transport of fly ash to markets in or near coal mines. At the same time, opportunities in other markets, including civilian and military government applications, have come to light during CIC development. It is believed that the investment by the DOE in developing this container system will be paid back many-fold as new environmentally cleaner waste-reuse markets capitalize on the advantages presented by SEEC's CIC system.

APPENDIX

100 Ton Triple Hopper Car
Stress Analysis
for

Report No. SEEC-940725

(Project No. 2961)

Prepared by: Joseph B. Raidt P.E.
Keith A. Miller
Approved: Roger D. Sims, P.E.
Date: July 25, 1994

100 Ton Triple Hopper Car

Stress Analysis

for

Report No. SEEC-940725

(Project No. 2961)

Prepared by: Joseph B. Raidt P.E.
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Approved: Roger D. Sims, P.E.
Date: July 25, 1994

Executive Summary

The loading of a typical triple hopper car with three SEEC Collapsible Intermodal Containers has been studied using state-of-the-art finite element analysis techniques. These techniques included non-linear large deflection analysis of the CIC and linear analysis for the car body and CIC combined model.

Three separate load cases used to analyze the car were 1,000,000 lb. buff loading, 630,000 draft and lateral load, and impact.

Under linear analysis, all car components performed adequately, with the exception of the intermediate floor sheet. The FEA model did not utilize large deflection and membrane action of the sheet. Classical analysis revealed membrane action significantly reduced the stress of the part.

Table of Contents

1.0 Introduction

The feasibility of loading existing hopper cars with the SEEC Inc. Collapsible Intermodal Container (CIC) was studied. The effects of the CIC devices on the car structure were studied using finite element analysis. The car used for the model was a Chessie System 100 ton triple hopper (Drawing No. 139-11-858). The CIC was modeled integrally with the hopper car.

This car is typical of most 100 ton open top hopper cars built by many carbuilders and railroad shops. It is typical of the "committee" car design as well.

As a byproduct of this study, the CIC was analyzed independently of the railcar as well to simulate its handling between transportation modes.

2.0 Procedure

2.1 Basic Railcar Model Description

A finite element model was constructed for the analysis (see Figures 1 and 2). The car components were composed of beam or plate elements.

2.1.1 Beam elements

- center sill bottom flange
- bolster top flange
- bolster & crossridge top flange at floor sheet
- crossridge top & bottom flange
- end slope sheet flange at side sheet
- hopper sheet flange at side sheet
- bolster bottom flange
- side sill
- side & end plate
- end diagonal brace
- side diagonal brace

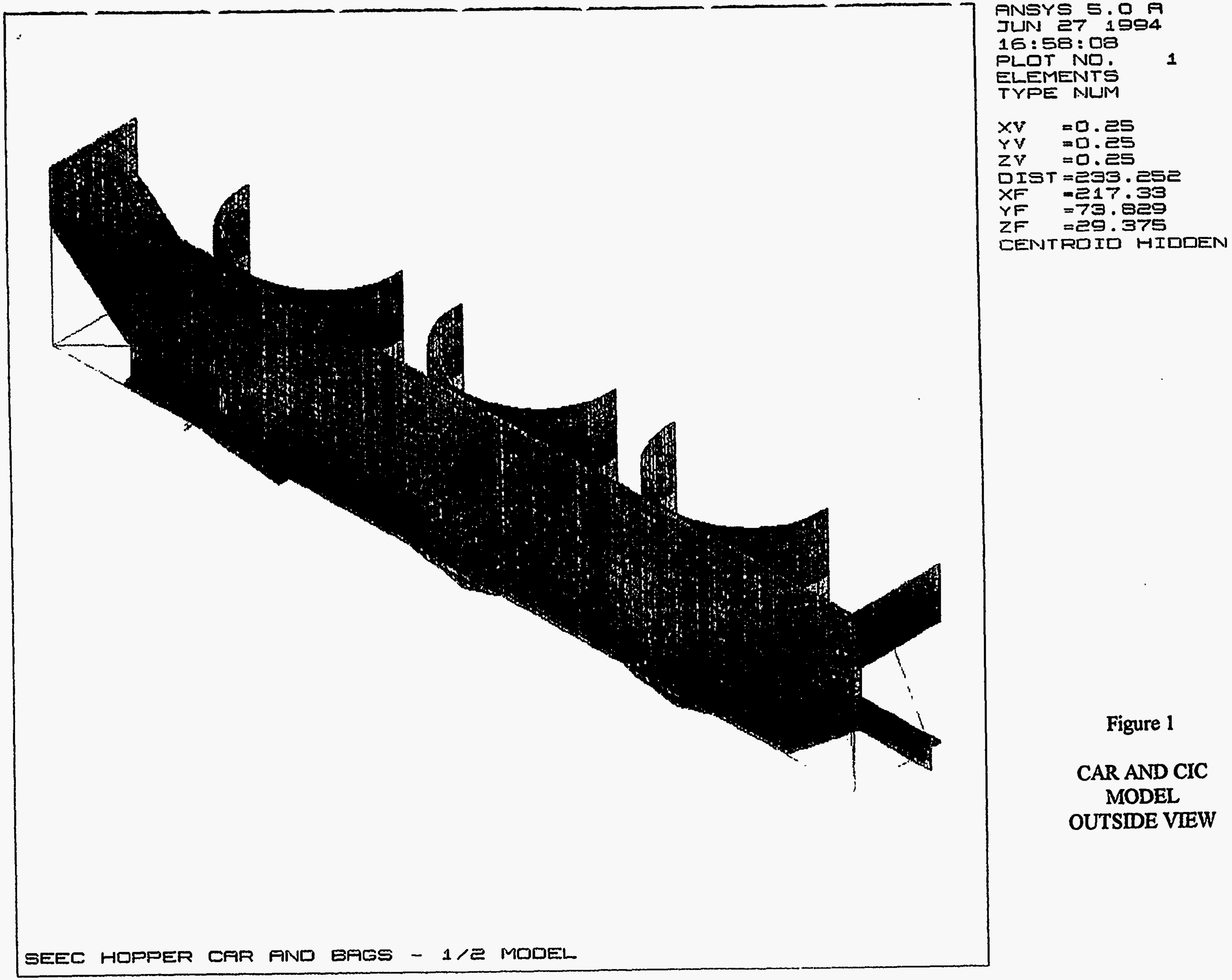

Figure 1

CAR AND CIC MODEL OUTSIDE VIEW

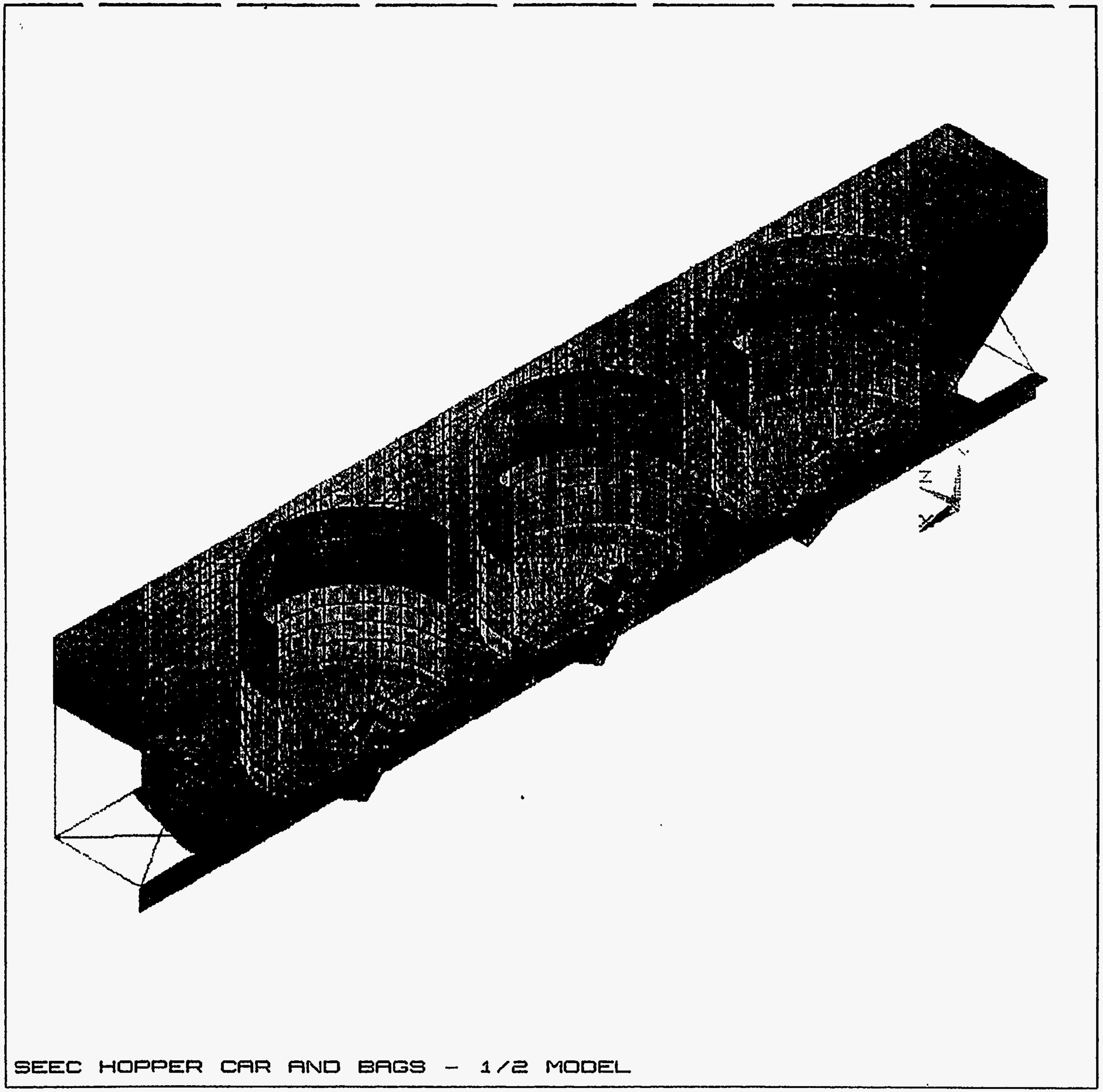

Figure 2

CAR AND CIC MODEL INSIDE VIEW

- end floor sheet transverse stiffener
- end floor sheet brace
- floor support
- side stake
- corner post
- end sill

2.1.2 Plate elements

- center sill top flange
- center sill web
- draft sill web
- side sheet
- hopper sheet
- end floor sheet
- intermediate floor sheet
- center sill hood
- bolster web
- bolster gusset
- crossridge web
- crossridge gusset
- shear plate
- end sheet
- bolster side bearing gusset

2.2 Basic CIC Model Description

An integral part of the railcar model is a finite element model of the CIC. The CIC model consists of the following components:

- CIC bottom
- CIC lower
- CIC upper
- 4" webbing
- 6" webbing
- single cord beam
- double cord beam

2.3 CIC Model Details, Boundary Conditions and Loading

A half CIC model was developed with symmetrical boundary conditions along the longitudinal centerline. The CIC was modeled with plate bending and membrane elements assuming thickness of 0.5 in. Modulus of elasticity was calculated from given material breaking strength, strain at the break point and the assumed thickness.

Three different portions of different material composition were used in the CIC model. The bottom portion of the CIC used plate elements which represented the membrane stiffness of the two ply Kevlar cord with plies 90 degrees to each. The middle portion used plate elements, which represented the membrane stiffness of the CIC, and used elements spaced 10 inches vertically, which represented the strength of the double cord in the circumferential direction. The upper portion used plate elements, which represented the membrane strength of the CIC, and used beam elements every 10 inches vertically, which represented the strength of the single cord in the circumferential direction.

The top portion of the CIC above the single cord wrap was not included in the model since it is weak in comparison to other portions. Tension spar elements were used to represent the 4 and 6 inch wide webbing. A thickness of 0.1 inch was assumed and a modulus of elasticity was calculated from given breaking strength, strain at break point and the assumed thickness. A steel beam was used to connect the lower webbing elements to the upper webbing elements.

When the CIC was analyzed separate from the railcar, it was supported vertically at the top of the steel beam. It was loaded to 20,000 lbf (half CIC) using a fluid pressure on the plate elements equal to lading weight density times the height from the top of CIC. This loading represents a full CIC carrying 20 tons of lading. A large deflection analysis was used in which increments the load in sub-steps with iterative convergence obtained for each step.

2.4 Car and CIC Model Details and Boundary Conditions

A half car and CIC model was developed with symmetry boundary conditions along the longitudinal centerline. The car was modeled using plate bending & membrane elements and beam elements (reference section 2.1 above). Three half CICs were also modeled with the half car model. Those models were similarly to the lone half CIC model with the exception of the bottom which now conformed to the shape of the center sill hood and slope sheets. A steel beam was added to connect the steel beam (connecting the webbing elements) to the side plate. The joint at the side plate was a pinned connection. This model was used to analyze all loads except the lateral load case (see below).

The impact case was revised to include releasing the CIC pinned connection to the side plate in the longitudinal direction. Friction forces in the longitudinal direction were applied at the pinned connections. They were equal to the resultant load calculated from previous vertical and lateral pinned connection forces times the coefficient of friction of 0.3. Loading for the impact case included pitching of the car which causes vertical dynamic lading pressure load on the bottom of the CIC, an increased longitudinal lading pressure on the impact end of the CICs and an acceleration on the car body.

A full car and CIC model was developed for the lateral load case. The model is the same as the half car model described immediately above except made full in order to accept the non-symmetrical lateral load.

2.5 Load Conditions

The car was analyzed using three separate load cases. The load cases represent worst case scenarios based on previous work and AAR Specification CII, Volume 2.

2.5.1. Dead load plus live load plus 1,000,000 lbf

buff load

2.5.2 Dead load plus live load plus 350,000 lbf draft load all subjected to a 1.8 load factor plus 0.45G times the lateral load.

The 0.45G lading load equals 18,000 lbf per CIC was applied to one side of the CICs in addition to its 1.8 vertical load. The car body was accelerated lateral 0.45G.

2.5.3 Dead load plus live load plus 1,250,000 lbf impact load.

The impact case included a 12 psi pressure on the slope sheet at the impact side of the sheet and 3 psi uniform pressure on the side sheets. The car was then accelerated to produce a 1,250,000 lbf load at the draft pocket.

2.6 Finite Element Analysis Code

The analysis was performed using ANSYS, a finite element analysis program capable of solving large structural models consisting of symmetrical and unsymmetrical beam elements, plate bending and membrane elements, and/or solid elements. ANSYS has the capability to solve models using either linear or non-linear methods.

The model which includes the car and the CIC was analyzed using conventional linear analysis. The forces were applied as described above and the reactions were checked for static balance.

The stand alone CIC model utilized non-linear analysis methods in ANSYS. The program applies the load in incremental steps which allows the deflected shape to alter the structural mechanism which reacts the applied loads.

3.0 Data and Results

Following is a stress summary listing maximum stresses, material strengths, margins of safety and the load case which causes the maximum stress (See Tables 1-3). Stress plots graphically depicting stresses are also included (see Figures 3-9).

TABLE 1

Car Body Stress Summary

Item	Max. Stress	Allow. Stress	M.S.
Center sill bottom flange	-46574	50000	0.07
Bolster top flange	5646	36000	5.38
Bolster and crossridge to flange at floor sheet	-20012	27500	0.37
Crossridge top and bottom flange	-6825	36000	4.27
End slope sheet flange at side sheet	1584	50000	30.57
Hopper sheet flange at side sheet	5599	50000	7.93
Bolster bottom flange	4242	36000	7.49
Side sill	37012	50000	0.35
Side & end plate	-21193	50000	1.36
End diagonal brace	-13386	36000	1.69
Side diagonal brace	-11125	58000	4.21
End floor sheet transverse stiffener	21331	36000	0.69
End floor sheet brace	12256	36000	1.94
Floor support	-36000	58000	0.61
Side stake	-24288	58000	1.39
Corner post	-20040	36000	0.80
End sill	30238	50000	0.65
Center sill top flange	31694	50000	0.58
Center sill web	46935	50000	0.07
Draft sill web	26149	50000	0.91
Side sheet	18360	50000	1.72
Hopper sheet	35490	50000	0.41
End floor sheet	7593	50000	5.59
Intermediate floor sheet	44138	70000	0.59
Center sill hood	47098	50000	0.06
Bolster web	28426	36000	0.27
Bolster gusset	25894	33000	0.27
Crossridge web	11229	36000	2.21
Crossridge gusset	26495	33000	0.25
Shear plate	16876	33000	0.96
End sheet	24277	70000	1.88
Bolster side gusset	12105	36000	1.97

Condition A: Dead Load + Live Load +1,000,000# Buff
Condition B: 1.8(Dead Load + Live Load + 350,000# Draft) + .45G Lateral
Condition C: Dead Load + Live Load + 1,250,000# Impact

TABLE 2

CIC with Car Body Stress Summary

CIC Member	Max. Strength	Allow. Strength	M.S.
4 inch webbing	556	5000	7.99
6 inch webbing	26	5000	191.31
Single cord circumferential (upper CIC)	742	4000	4.39
Double cord circumferential (middle CIC)	301	4000	12.29
Bottom CIC section	1247	4000	2.21
Middle CIC section	326	1200	2.68
Top CIC section	218	1200	4.50

TABLE 3

CIC Static Load Stress Summary

CIC Member	Max. Strength	Allow. Strength	M.S.
4 inch webbing	474	5000	9.55
6 inch webbing	452	5000	10.06
Single cord circumferential (upper CIC)	167	4000	22.95
Double cord circumferential (middle CIC)	79	4000	49.63
Bottom CIC section	522	4000	6.66
Middle CIC section	121	1200	8.92
Top CIC section	121	1200	8.92

Condition A: Dead Load + Live Load +1,000,000# Buff
Condition B: 1.8(Dead Load + Live Load + 350,000# Draft) + .45G Lateral
Condition C: Dead Load + Live Load + 1,250,000# Impact

Note: Stress values taken from ANSYS model runs have been converted to strength values (lb/in of width) by multiplying stresses by assumed thicknesses.

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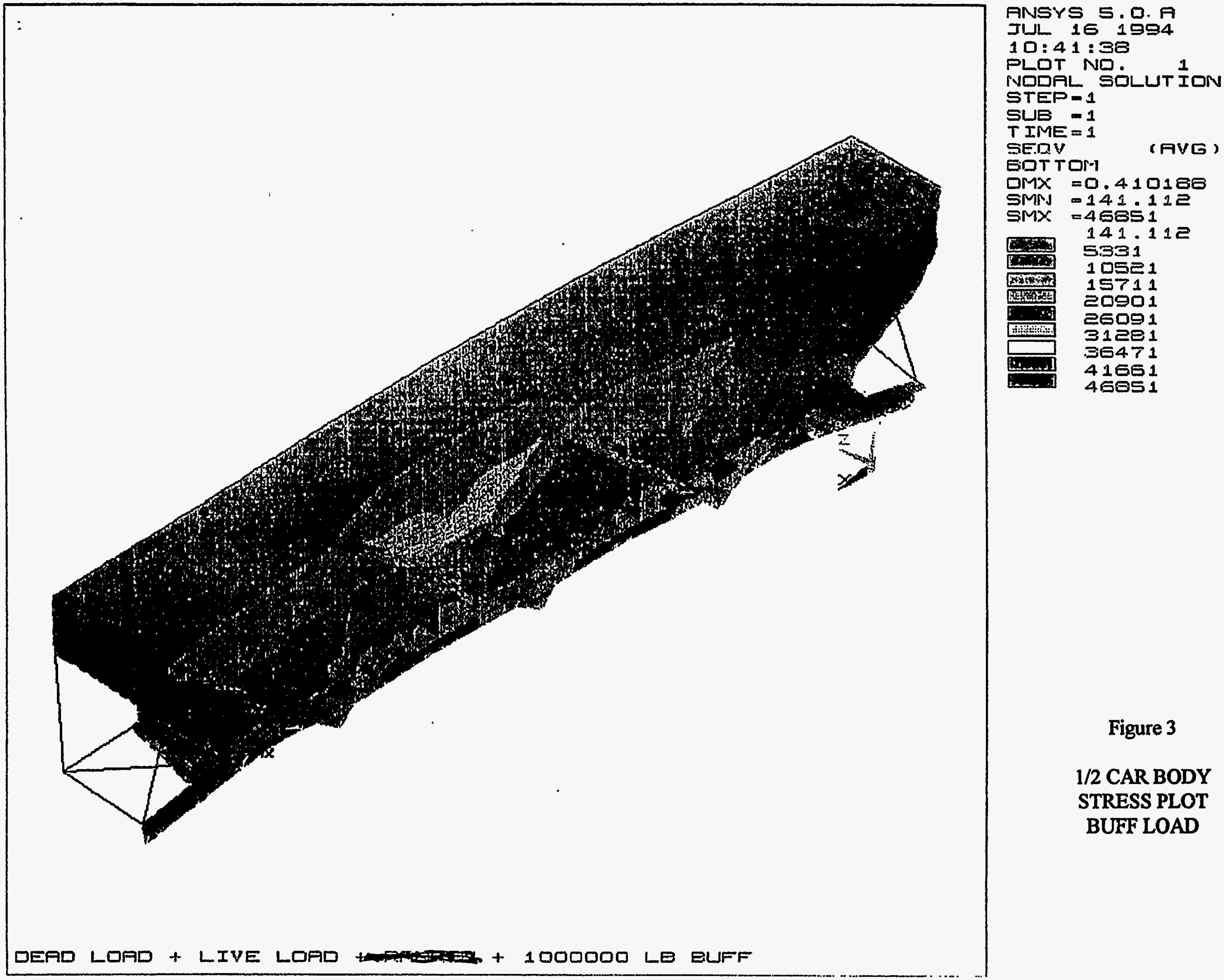


Figure 3

1/2 CAR BODY
STRESS PLOT
BUFF LOAD

Multiply above stresses (#/in²) by 0.5 in. thickness to obtain breaking strength (#/in).

Figure 4

1/2 CIC MODEL STRESS PLOT BUFF LOAD

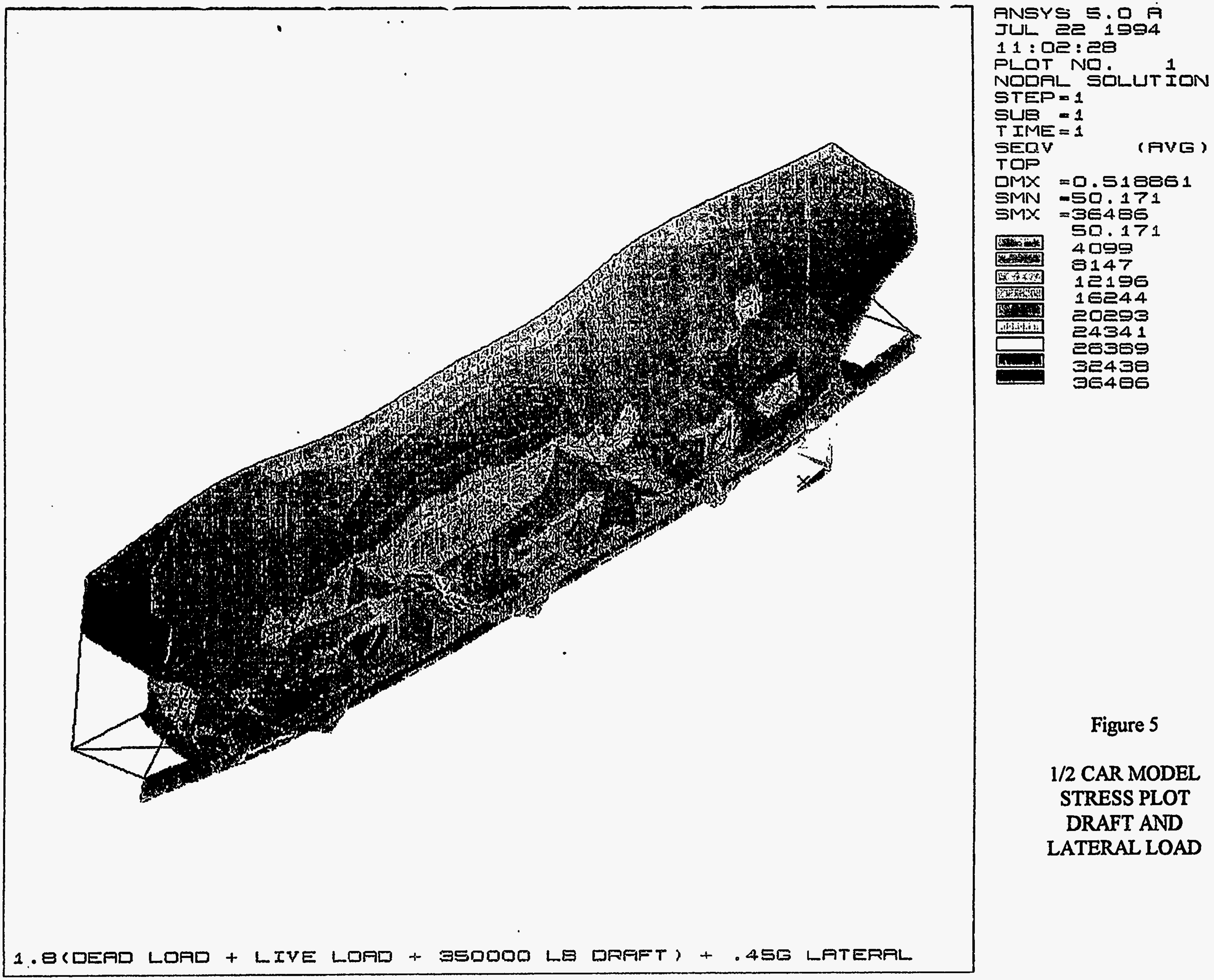


Figure 5

1/2 CAR MODEL
STRESS PLOT
DRAFT AND
LATERAL LOAD

Multiply above stresses (#/in²) by 0.5 in. thickness to obtain breaking strength (#/in).

Figure 6

1/2 CIC MODEL STRESS PLOT DRAFT AND LATERAL LOAD

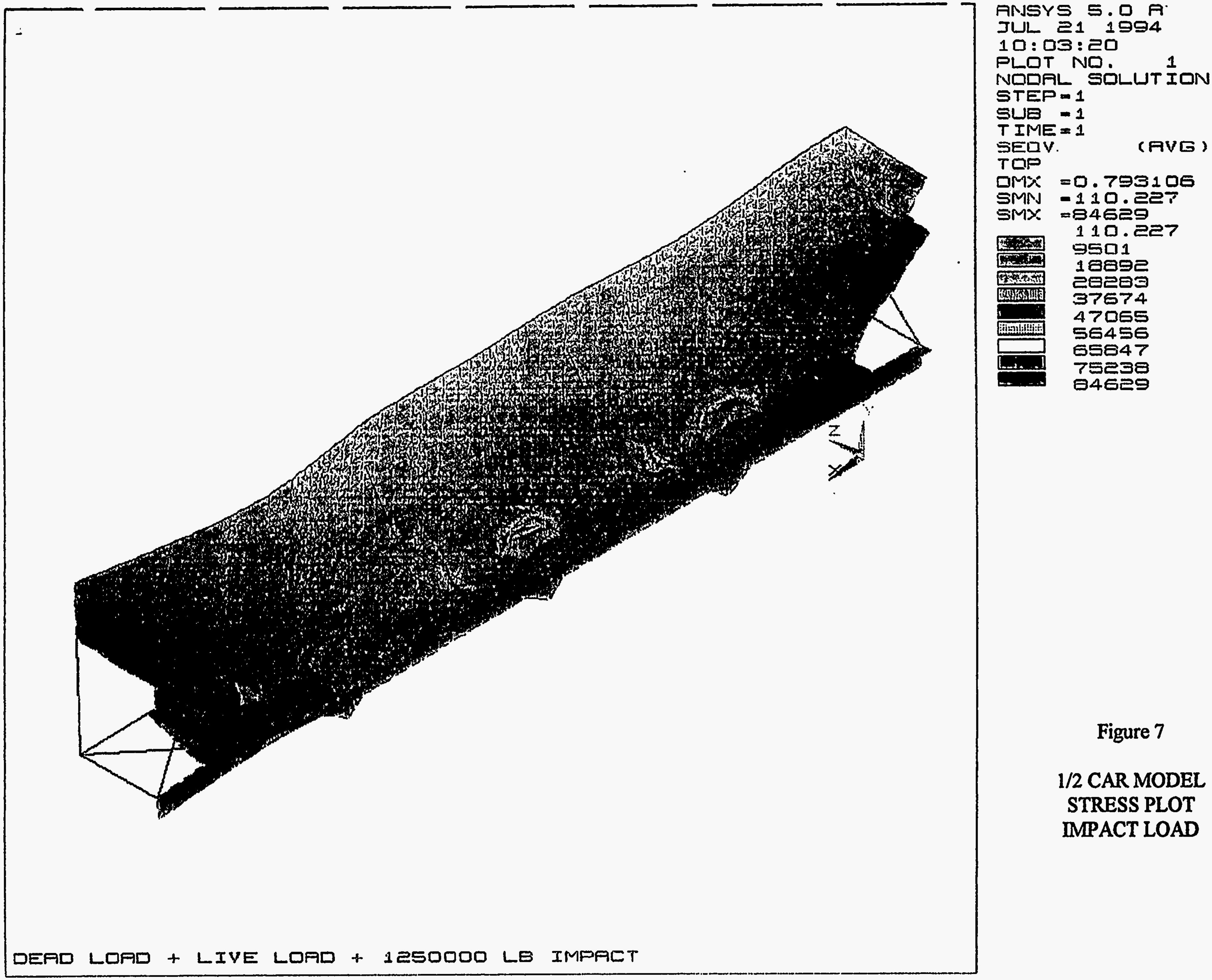


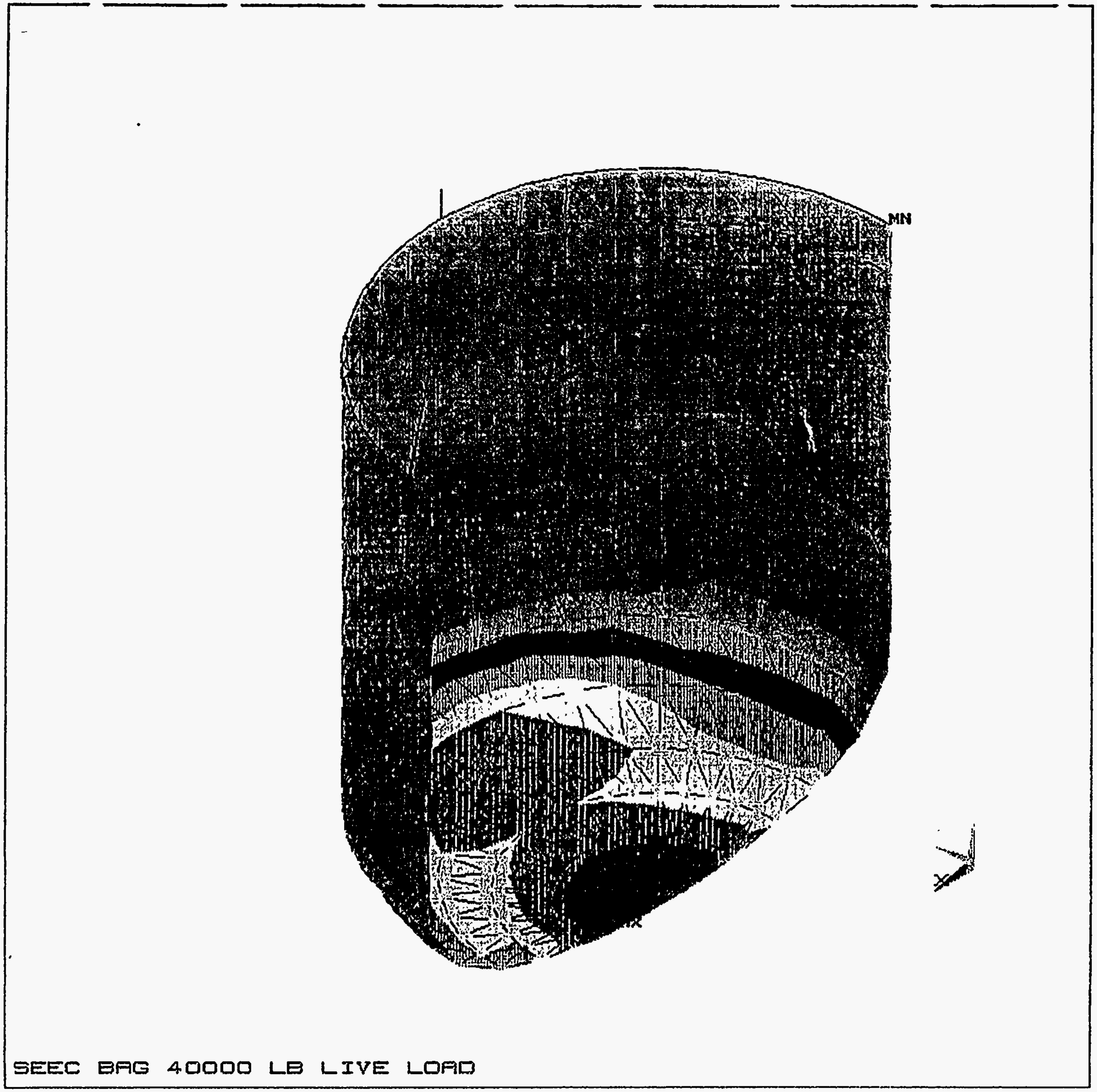
Figure 7

1/2 CAR MODEL
STRESS PLOT
IMPACT LOAD

Multiply above stresses (#/in^2) by 0.5 in. thickness to obtain breaking strength (#/in).

Figure 8

1/2 CIC MODEL
STRESS PLOT
IMPACT LOAD



Multiply above stresses (#/in^2) by 0.5 in. thickness to obtain breaking strength (#/in).

Figure 9

1/2 CIC MODEL
STATIC LOAD
STRESS PLOT

4.0 Conclusions

All car components in the finite element analysis have acceptable margins of safety, with the exception of the intermediate floor sheet and the floor support. The floor support was found to have stress levels at yield, but use of the plastic section modulus reveals the ultimate member strength is not exceeded and is, therefore, acceptable.

The intermediate floor sheet under linear analysis was shown to have high stresses. However, in real world application, the sheet would benefit from membrane action due to its large deflection. Additional classical large deflection analysis revealed that the floor sheet is not overstressed. Therefore, each of the two critical components are found to be sufficient for the load cases described.

The CIC has high margins of safety when analyzed separately from and in conjunction with the car.