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STABILITY EVALUATION OF THE PANEL 1 ROOMS AND THE E140 DRIFT AT WIPP

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FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

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1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is intended to be an underground geologic repository for permanent disposal of defense transuranic (TRU) radioactive waste, being constructed and managed by the U.S. Department of Energy (DOE). The facility is located 40 km east of Carlsbad at a depth of 655 meters in the salt beds of the 600 meters thick Permian Salado Formation. The repository will consist of 56 "rooms", each 91.5 meters long, 10 meters wide and 4 meters high (300 ft x 33 ft x 13 ft), grouped in eight "panels" of seven rooms each (Figure B-1). These rooms and approximately 7.5 km (4.7 miles) of access drifts will provide sufficient space to accommodate 176,000 cubic meters (approximately 850,000 fifty-five gallon drums equivalent) of contact-handled (CH-TRU) and 7100 cubic meters (approximately 7,500 canisters) of remote-handled (RH-TRU) waste. The CH-TRU waste will contain approximately nine million curies of radioactivity, and the RH-TRU approximately five million curies.

The CH-TRU waste will arrive mostly in 55 gallon carbon steel drums and some standard waste boxes. The drums will be in seven-packs that will be stacked three-high in the rooms and drifts, approximately 6000 drums per room and the rest in the drifts. The RH-TRU waste will arrive and will be disposed in shielded right circular cylinders made of 6.35 mm (1/4 inch) carbon steel plate with 0.66 meter (26 inches) outside diameter, an overall length of 3.07 meters (10 feet, 1 inch) and an inside volume capacity of 850 liters (30 ft^3 or 224 gallons). The RH-TRU canisters will be placed in 0.91 meter (36 inches) diameter horizontal boreholes drilled in the walls of the disposal rooms and drifts at 2.44 meter (8 feet) centers. The impact of emplacement of RH-TRU

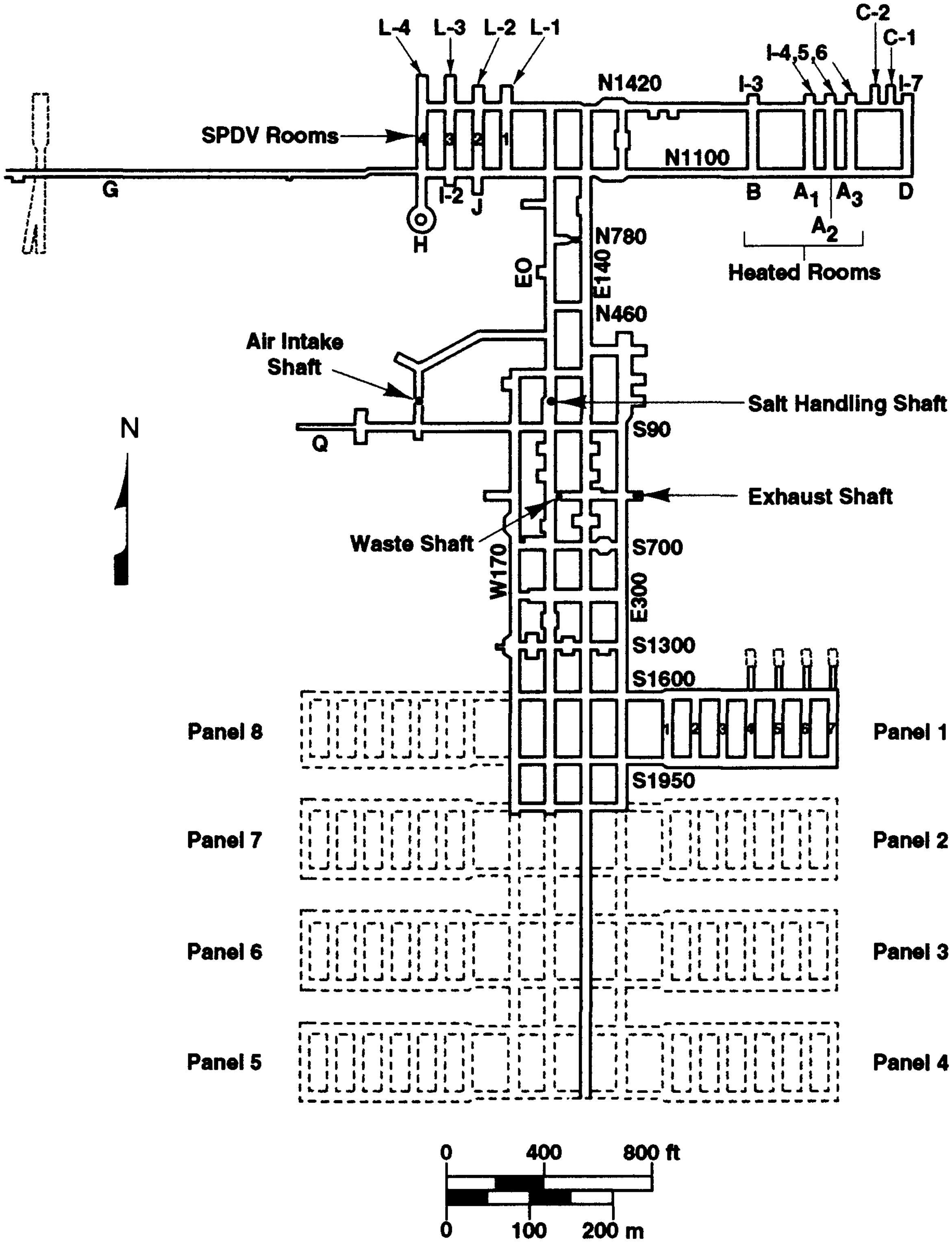

Figure B-1. Underground layout of the WIPP repository.

waste has not been considered in this report because the RH-TRU waste will not be available for disposal at least until 2002 and thus will most likely not be placed in panel 1.

2.0 PREMATURE FACILITY EXCAVATION

The excavation of the repository began in 1982 and all the surface facilities including the four shafts have been completed. All underground access and test facilities and one out of eight waste repository panels were excavated by 1988. Thus, the facility was excavated many years before it could be used.

The design life for the WIPP facility was 25 years (U.S. DOE 1984, p. 1-1). The current plans are to start emplacing waste in the facility in 1998 and continue for 35 years, i.e., until the year 2033. That would be 51 years from the beginning of excavation of the facility in 1982, and 45 years from 1988 when all the underground excavations including shafts had been completed, except the remaining seven panels of the repository.

The north-south drift E140 is the widest (25 ft) of the four main north-south drifts in the WIPP underground and is the main north-south passage through the facility. It will be used to transport the waste from the base of the waste shaft to the repository panels. It was excavated in 1982 to the southern extent of the designed excavations, to south 3650 (3650 ft from the salt handling shaft), but it was blocked south of the S. 2180 drift soon afterwards.

The repository panel 1 was excavated from 1986 to 1988, because the DOE planned to start some experiments with waste in the repository in 1988. For reasons beyond the scope of this report, that plan did not materialize and the DOE finally abandoned the plans to conduct experiments with waste in 1993. Thus, instead of the original plan to emplace and retrieve waste from these rooms after a 5 year experiment/demonstration period, by 1993, the rooms are now expected to remain open at least until 2005.

3.0 PREDICTED VERSUS OBSERVED CLOSURE RATES

In addition to the premature excavation of the facility, the observed closure rate of the excavations turned out to be several times the predicted (design) rate, thus reducing the time for which the excavations would remain stable without support. Before underground excavations at WIPP began in 1982, the DOE scientists performed calculations to predict the closure history of the excavations. These calculations used the geomechanical properties of the rock strata at the selected WIPP repository horizon determined from testing rock cores obtained from boreholes. The calculations predicted that a WIPP room would "close slowly in a stable manner as the salt creeps" and "relative closure values of 0.21 meters in the vertical direction and 0.28 meters total in the horizontal direction are seen for the isothermal[1] room after 10 years." (Miller, Stone and Branstetter 1982).

Although the closure rates change with time and vary within the WIPP excavations and therefore a simple comparison is difficult to make, the observed closure rates are at least three times larger than the predicted values (Morgan, Stone, and Krieg 1985, 1986). Munson, Fossum, and Senseny (1989 p. 2) explained:

> Morgan et al. (1986) demonstrated through a parametric study that the discrepancy could not be the result of known uncertainties in steady-state creep parameters or clay seam friction values, but was more deeply rooted. This discrepancy created a fundamental problem with the ability to make tightly argued technical assurances of the times of room and shaft closures for repository and seal performance assessment.

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[1]Isothermal here means non-heated. Some test rooms at WIPP were heated to simulate and study the effect of heat from the high-level waste in the 1980s because the DOE had planned to temporarily store some high-level waste at WIPP.

A Modified Multideformation Model, also known as the Modified Munson-Dawson model (M-D model) has attempted to simulate the observed vertical closure (Munson, Fossum, and Senseny 1989). However, the design of the excavations and the plans to use them were made on the basis of the original predictions and therefore little comfort can be derived from later fitting a model to the data. The repository room dimensions of 4 meters high and 10 meters wide (13 ft x 33 ft) was based on calculations using laboratory-derived average creep parameters. This design allowed for 30.5 cm (12 inches) of vertical closure and 23 cm (9 inches) of horizontal closure five years after excavation (U.S. DOE 1986, p. 16). Observed average vertical convergence for the first five years in the panel 1 rooms was, however, about 0.5 meter (19.4 inches), and the observed average horizontal closure was about 35 cm (13.7 inches).

4.0 ROOF FALLS

Four "Site and Preliminary Design Validation (SPDV) Rooms" were excavated in the northern experimental area of the WIPP (Fig. 1) in March/April 1983 to study the geotechnical behavior of the WIPP repository rooms. These rooms were placed in the same stratigraphic horizon as the WIPP repository and were of the same dimension as the planned repository rooms. By 1986, the SPDV rooms started showing signs of deterioration. Extensive fractures developed in the roof, walls and floors of rooms 1 and 2 (U.S. DOE 1987). While drilling for the installation of roof bolts in SPDV room 1 in April 1989, the WIPP project personnel encountered dust coming out of the previously drilled holes in the roof, up to 15 meters apart. Discovery of extensive fracturing above the roof of the SPDV rooms in April 1989 led to the restriction of access to these rooms in May 1989.

A rock slab, approximately 15,000 tons, detached from the roof of room 1 and fell to the floor on February 15, 1991, less than eight years after the room was excavated. A similar roof fall occurred in the SPDV room 2 in June 1994. Other roof falls occurred in the experimental heated rooms A-1, A-2 and A-3 during the 1990-91 period. The higher than expected rates of closure and the roof falls caused concern about the stability of the underground excavations.

5.0 PANEL ONE ROOMS AND THE STABILITY ISSUE

The first of the planned eight panels of the WIPP repository was excavated in two stages. The panel entry in S 1950 drift, room 1, and parts of rooms 2 and 3 were excavated between May 1986 and March 1987. Mining restarted in January 1988 and the panel excavation was completed to final dimensions in June 1988. These rooms were excavated for emplacement of 55 gallon drums of CH-TRU waste for an operational demonstration, starting in October 1988. They were fitted with 10 ft long anchor bolts at 4 ft spacing in the roof to keep the rooms open for up to seven years. It was planned to emplace up to 6,000 drums in each room and to start retrieving them by October 1993. Even before the rooms had been completed, it became clear that they would not be used for the original purpose and the waste would not start arriving in 1988. By 1990, the plan was to use only one of these seven rooms for the "Bin Tests", which unlike the storage plan, required continuous access of the room by scientific and maintenance personnel. Based on "qualitative evaluations", the project "estimated that Panel 1 has a useful life of 7 years beyond June 30, 1990, with an estimated total roof to floor closure of 50 inches." (U.S. DOE 1991a, p. 2-7). In 1993, the DOE abandoned the plans to use these rooms for experiments with waste. The plan now is to use them for permanent disposal of waste starting in 1998.

6.0 GEOTECHNICAL EVALUATION

The DOE assembled a group of 11 geotechnical experts (including one Sandia National Laboratory and two Westinghouse employees) in April 1991 for advice on the stability of the panel 1 rooms and increasing their useful life span. The group of experts concluded:

> If no additional remedial measures are taken, the rooms in the panel are likely to have a total life from seven to eleven years from the time of excavation using the currently installed roof support system, consisting of rockbolts. They indicated that the rockbolt had some beneficial effects, but agreed that it was not possible to measure their effectiveness. Estimates made by individual panel members of room life extension due to the bolting varied from a few months to several years. In conclusion, the panel believed that modifications, enhancements, and regular maintenance would be required for the rooms in panel 1 to perform satisfactorily over the assumed nine-year test period starting July 1991. (U.S. DOE 1991b, Executive Summary, page v).

In other words, the rooms could remain stable without additional support for a period of 2 to 6 years from April 1991, i.e. until 1993 with high confidence and until 1997 with decreasing confidence (U.S. DOE 1991c, p. 5-2).

7.0 SUPPLEMENTARY ROOF SUPPORT SYSTEM

Based on the recommendations of the Geotechnical Panel, an elaborate "supplementary roof support system" was designed and installed in the room 1 of panel 1. It was decided to install this system in only one of the seven rooms because by 1991, the DOE plans for experiments with waste had shrunk to include only 12 bins of waste. The purpose of this ground support system was to "extend the life of room 1 to allow completion of the experiments, for an additional period of up to seven years (from July 1991)." (U.S. DOE 1991c, p. 1-2). The system consists of additional roofbolts, steel channel beams, lacing cables and wire meshing. Each of the 286 roofbolts was fitted with a load cell for continuously monitoring the performance of the roofbolts.

The system is not designed to prevent the creep of rock into the room, but to contain and support the detaching roof slab while allowing it to be lowered. Most of the load of the detaching roof is carried by the rockbolts. An important element of this design is that the bolts are to be periodically detensioned when the load on them reaches 20,000 pounds. For the past several years, the frequency of detensioning is about once a month.

All the rooms of panel 1 were fitted with 3 meters (10 ft roof) long pattern bolts in 1988-89. Room 7 was rebolted in 1993 with 1.8 meters (6 ft) pattern bolts. In addition, a supplementary support system (a variation of the room 1 system) was installed in room 2 in 1991. Thus, the rooms 1 and 2 have the supplementary roof support system, but Rooms 3 through 7 have only the original and some additional roofbolts and wire meshing. The convergence rates in the panel 1 rooms are slightly higher than those observed in the SPDV rooms at the comparable time (U.S. DOE 1993b).

In addition to the roof stability problems, all the rooms also face problems due to floor heave and spalling of the walls of the rooms, for which periodic maintenance is required.

8.0 PANEL 1 UTILIZATION PLAN

The Panel 1 Utilization Plan was presented at a meeting of the "WIPP Stakeholders" on May 19, 1994, and was published in December 1994 (Westinghouse 1994).

The major reason presented for DOE's plan to continue using panel 1 rooms for waste disposal was that it would not be wise to excavate panel 2 until the DOE is certain that it would be used for waste disposal. The DOE engineers insisted at the meeting that it would take three years to excavate a new panel and that would cause an unacceptable delay between getting all the approvals and starting waste emplacement at WIPP. The EEG pointed out that the four SPDV rooms were excavated in six weeks, between March 9, 1983, and April 25, 1983, and the panel 1 was excavated in a total of 15 months even with an interruption of nine months between the two phases of excavation. In fact, "Rooms 4 through 7 were completed, in 1988, within approximately one month after the start of excavation." (U.S. DOE 1991a, p. 2-6). If four rooms can be excavated in one month, then why can't seven rooms be excavated in two months? Including the time for excavating the access drifts, it is difficult to understand why a new panel cannot be excavated during the 180 day statutory waiting period required by the WIPP Land Withdrawal Act [Public Law 102-579, Sec. 7(b)(3)], after all the requirements for commencing disposal operations are completed.

9.0 ISSUES TO BE RESOLVED BEFORE USING PANEL 1 FOR DISPOSAL

The DOE decided in October 1993 to abandon the plan for conducting experiments with waste in the panel 1 rooms and to pursue an accelerated schedule for demonstrating compliance with the EPA Standards. The plan now is to complete all the requirements by October 1997 and to begin CH-TRU waste disposal at WIPP in April 1998. Even if this very aggressive schedule can be met, the following issues will have to be satisfactorily resolved before using the Panel 1 rooms for disposal:

9.1 Safe Life of the Rooms

What is the safe life of the rooms with a supplementary roof support system? The design report for the system stated the goal was to "extend the life of Room 1 to allow completion of the experiments, for an additional period of up to seven years (from July 1991) (U.S. DOE 1991c). The project has claimed that the room 1 support system was installed to minimize the need for ground control activities during radioactive waste experiments; otherwise, the rooms can be kept stable by ground control activities. Since the process of waste emplacement will not allow frequent ground control activities, it is obvious that supplementary roof support systems will have to be installed in rooms 2 through 7 if these rooms are to be used.

The DOE has claimed, "The minimum life of the installed support system is estimated at 15 years based on the highest roof expansion rate experienced to date" (U.S. DOE 1993a). This statement was based on the remaining 21.6 cm (8.5 inch) length of the roofbolt "tails" available for adjustment and the assumption that the 1.4 cm (0.56 inch) roof expansion during the first year would remain constant for 15 years, and without considering the effect of lateral offset. If the roof expansion rate changes, the estimate would change. Similarly, a critical factor in the predicted stability of the roof support system is the assumption that separation at the anhydrite "a" layer, 4 meters (13 ft) above the roof, would not be such that the whole 4 meter (13 ft) beam becomes unstable. The system is anchored below the anhydrite "a" horizon.

9.2 Feasibility of Maintenance During Waste Operations

All excavated areas require periodic maintenance. In areas without roof support, it consists of removing the unstable parts of the roof. In areas with roof bolts, the broken bolts have to be replaced, and some areas are bolstered with additional bolts. The system as presently installed in Room 1 is designed not to prevent the fracturing and separation of a 2.1 meter (7 ft) layer of rock above the roof (Figure B-2), but to hold it suspended using the support structures. This design requires periodic detensioning of the roofbolts, currently about once a month. Periodic stabilization of the drummy areas of the walls will be necessary and the floor also has to be periodically milled and the cracks filled using crushed salt. The DOE position on the Panel 1 safety is as follows:

"Panel 1 is safe and can be maintained in a safe condition indefinitely <u>as long as maintenance can be performed</u>. (Westinghouse 1994 p. A-3, Underline added)

The obvious question then is: will it be possible to conduct the required maintenance activities, such as monthly detensioning of the roof bolts, while the waste is being emplaced? The EEG has been asking this question for the past several years but has not yet received a satisfactory answer from the DOE. While an accident analysis involving a roof fall has been included in the WIPP Safety Analysis Report (Westinghouse 1995), there is no description of how the waste emplacement operations can be carried out in the panel 1 rooms in which frequent maintenance is required. A detailed plan addressing

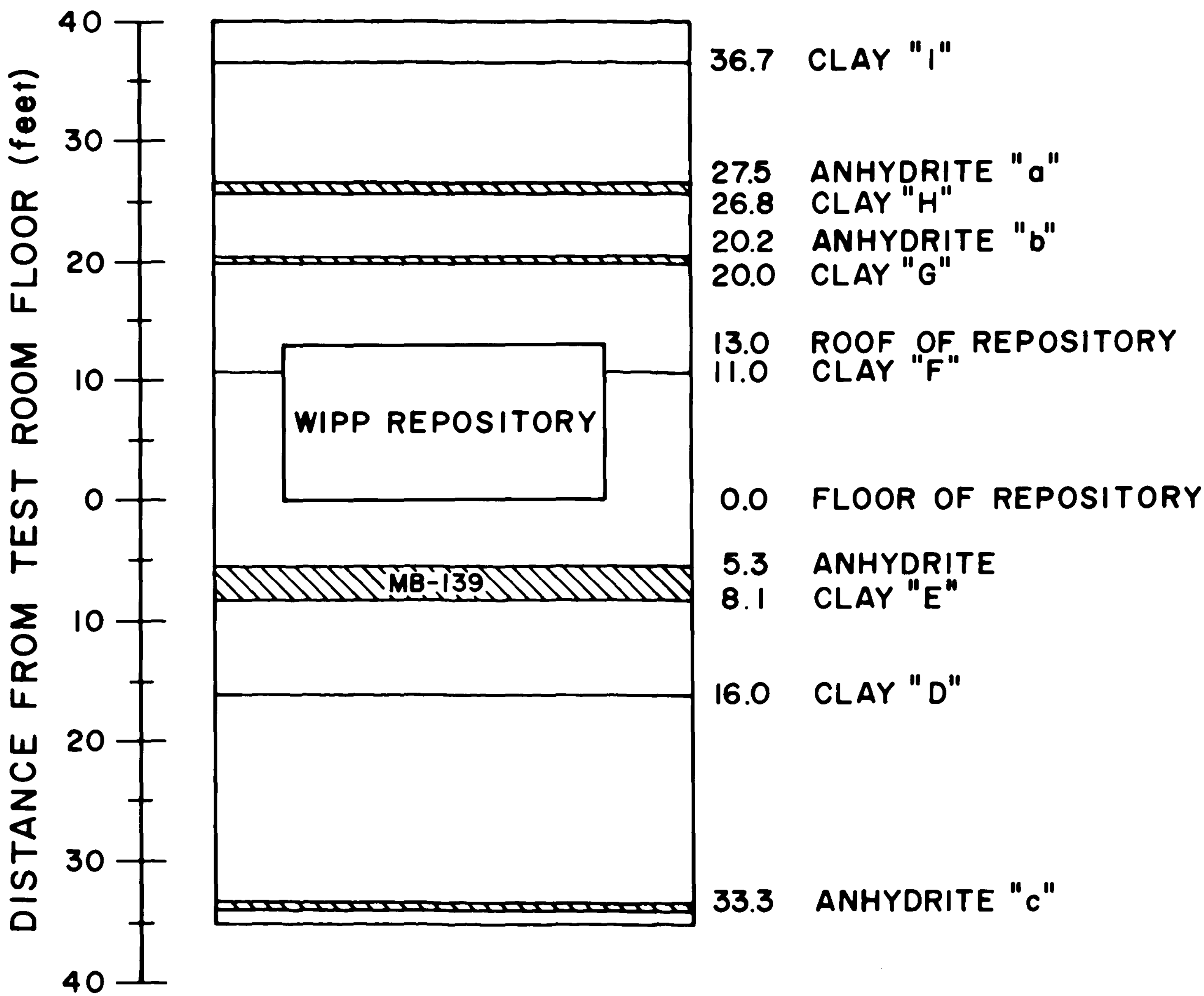

Figure B-2. Anhydrite and clay interbeds above and below the WIPP repository.

the resolution of the potential problems during the operations is required. Such a plan should be prepared as a joint effort between the mine safety and the radiation safety personnel of the project.

9.3 Impact of Introduction of Additional Metal in the Repository

One of the postulated mechanism of gas generation in the WIPP repository is hydrogen generation from corrosion of metals. Reduction of total metal content in the repository, even changing the steel waste container in favor of a non-metallic or less corroding metal container, has been proposed by the project scientists. Would it not be counter-productive to introduce additional metal in the form of roof support structures in the repository? This issue should be specifically addressed as a part of the WIPP performance assessment for the long-term.

9.4 Impact of Roof Support System on Closure Mechanism

The design concept of the repository is based on swift and uniform closure after waste emplacement, to "cocoon" the waste without leaving too much void space. How will this desirable closure mechanism be affected by the roof support system and what effect will it have on long-term performance of the repository?

9.5 Impact of Maintenance Operations on Performance

The potential for the anhydrite and clay interbeds to act as conduits for fluid flow has been recognized as a factor in the assessment of the WIPP repository to contain waste. Marker Bed 139 is located about 1.5 meters (5 ft) below the repository floor, and Anhydrite "a" and "b" layers and associated clay seams are located approximately 4 meters (13 ft) and 2 meters (7 ft) above the roof (Figure 2). The 1983 DOE evaluation of the WIPP Site and Preliminary Design Validation Program was used to qualify the WIPP site with respect to the "stratigraphy criterion" based on the following reasoning:

"Interbeds must also be evaluated with regard to their potential role in providing preferred pathways for fluids into or out of the TRU waste rooms. There are no such major interbeds within the horizon to be excavated for the TRU waste rooms. The nearest interbeds of significance are 10 ft above and 5 ft below the room. The permeability of the salt is low enough to prevent any connection between these interbeds and the waste rooms. The permeability of the interbeds is also quite small". (U.S. DOE 1983).

Does this statement remain valid for the panel 1 rooms, when: the interbeds above the roof have been allowed to be fractured; at least 286 connections have been made between the room and the fractured anhydrite "b" layer through roofbolts; and, the floor of the rooms is thoroughly fractured and connected with the underlying heavily fractured Marker Bed 139 through periodic milling of the floors?

9.6 Vertical Clearance of the Panel 1 Rooms

The design of the supplementary roof support system allows the roof to be lowered as it detaches from the rock above. Similarly, the floor heaves. This would result in progressively less operational vertical clearance with time. An analysis is needed for the expected available clearance in the post 1998 period versus the required clearance for disposal operations.

9.7 Stability of Excavations Other Than Panel 1

The shafts and drifts at WIPP were excavated during the early 1980s and were designed for a 25 year period. A large number of workers are required to perform maintenance and restoration operations in the mine, slabbing in the drummy areas, installing and replacing rock bolts, wire mesh, etc. If the disposal operations begin in 1998, these excavations and the shafts will be about 15 years old and will have to remain in service for another 35 years. It would be wise to assess now whether the facility can be used safely for much longer than the original design period of 25 years, starting 15 years after excavation, and if so, what restoration and maintenance will be required.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The EEG requested Dr. Hamid Maleki of Maleki Technologies, Inc. to assess the stability of the panel 1 and the E 140 drift during the first seven years of waste emplacement operations. For this analysis, we assumed the DOE projection of April 1998 to be the starting date for waste emplacement, but made a more realistic assumption of seven years to fill panel 1, rather than the 2.5 years projected by the DOE. The capacity of panel 1 is 81,000 CH-TRU drum-equivalent, plus RH-TRU that the DOE expects to be available for disposal in 2002. Dr. Maleki's analysis does not consider the radiological/worker safety issues and the difficulty of conducting maintenance operations in the rooms and the access drifts during the waste emplacement period. Based on mining safety considerations alone, Dr. Maleki concludes that while it would be possible to safely use portions of panel 1 for waste emplacement, it would be best to abandon panel 1 and mine a new panel after the decision has been made to use WIPP as a repository.

The WIPP facility was excavated much earlier than its intended use and requires continuous maintenance to be ready for operation until all other requirements for starting the operations have been satisfied. Clearly, new excavations for the repository should not start until needed. Judging from the past experience, a new repository panel can be excavated in less than 6 months. Since the DOE is required by the WIPP Land Withdrawal Act to wait for 6 months after all the approvals are obtained, a new panel can be excavated during that period. The EEG recommends abandoning panel 1 and excavating a new panel for waste emplacement, once all the necessary certifications and permits have been received, unless the DOE can demonstrate that the issues outlined in this report can be satisfactorily resolved.

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STABILITY EVALUATION OF THE E140 DRIFT AND PANEL 1 ROOMS AT WIPP

by

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1.0 INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is located about 30 miles east of Carlsbad, New Mexico. The site was authorized by Congress in 1979 as a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from defense activities. The current mission is to receive, handle, and permanently dispose of transuranic mixed waste (both contact and remotely handled) in underground workings (panels), located 2,150 ft below the surface within a nearly 2,000-ft-thick sequence of evaporites called the Salado Formation (Westinghouse 1995).

Development of underground workings has taken place in phases. Preceding each phase, there were engineering calculations by the project architect, followed by test mining and careful geotechnical evaluations with the purpose of characterizing the site and verifying the preliminary designs. This approach is suitable for mining projects where there are variations in geologic setting, material properties, stress fields, in situ pillar strengths, and bolting supplies, and where there are deficiencies in understanding the physics of natural phenomena, such as creep in salt rock.

The E140 drift, one of the main arteries of the facility for air supply and access, was mined during 1983, followed by mining and design verification in the SPDV area, which has geometric conditions similar to those in the waste panels, leading to development of Waste Panel 1 during 1986-1988. The mining schedule for Panel 1 was influenced by favorable short-term monitoring results in the SPDV area and initial schedule of waste arrival. Because of delays in receiving the waste, the average life of Panel 1 has been extended beyond the original functional life (5 years) to 17 years, based on current estimates of waste arrival (May 1998). Similarly, the active life of the E140 drift is now estimated to be 50 years (to 2035).

Prior to 1986, very few areas within the facility were roof bolted. Between 1986 and 1988, more than 9,000 bolts were installed in the facility, particularly in the E140 drift. By 1990, most areas in the underground facilities had been systematically bolted using 6- to 10-ft-long, grade- 75, mechanically anchored bolts (Peterson 1995). In 1991, a secondary support system, consisting of wire mesh, expanded metal, channel steel, and point-anchored, threaded rebar was installed in Room 1, Panel 1, to help extend the life of this room. Other secondary support systems, including mechanical bolts, resin-point-anchored threaded rebar (with and without slip nuts), cable bolts, and cable mesh, were installed in portions of Panel 1 and E140. In addition, a laboratory investigation was initiated to test and compare the load-carrying capacity of mechanical bolts and a variety of yielding cable bolts under the influence of combined tensile and lateral offset loading conditions.

To monitor ground conditions and study support performance, an intensive geotechnical monitoring program was implemented. This program consisted of monitoring strata deformation (Figure 1), bolt loads, locations where bolts failed, strata fracturing, and lateral offsets at clay G and other horizons. These measurements have been very helpful in improving understanding of strata behavior and in increasing the operator's ability to assess ground conditions and determine supplementary support requirements.

2.0 EVALUATION OF EXISTING GROUND CONDITIONS

This evaluation is based on a review of deformation data for Panel 1 and the E140 drift during a period prior to January 1996; underground observations of roof, floor, and rib conditions; a review of Excavation Effects program data; and bolt failure data.

Deformation data included in this analysis were extracted from plots and are summarized in Figures 2 through 5. The analysis consists of relative roof deformation (Figure 2), roof deformation rate in inches per year (Figure 3), total roof-floor convergence (Figure 4), roof-floor convergence rate in inches per year (Figure 5), and rib lateral-deformation patterns.

2.1 Roof Stability

The following preliminary criteria were used to assess roof conditions for Panel 1 and E140 entries that are between 8 to 13 years old.

- A roof deformation rate approaching 1.1 to 1.8 in/yr. These values were reached in unsupported portions of barricaded SPDV rooms several years before an intentional roof collapse. Thus, they are indicative of formation of roof slabs requiring supplementary support.

- A consistent increase in roof-floor convergence rate. Considering the age of the excavations, the convergence rate should decrease in time using the equations developed by Westinghouse Engineering (Westinghouse 1995). A significant increase (15%) in the convergence rate indicates abnormal roof and/or floor movement.

- Excessive (2 in) asymmetrical offsets at clay G or lower horizons and the presence of persistent shear and tensile fractures near the ribs are indicative of the formation of cantilevers in the mine roof (Figure 6). Because of the limited ability of mechanical bolts and threaded rebar to accommodate both high tensile and offset (bending) moments (Peterson 1995), this condition can be associated with a higher rate of bolt failure, leading to roof stability problems if adequate supplementary support is not installed in a timely fashion. Currently, failed bolts are replaced only with like bolts.

Tables 1 and 2 present the results and identify locations in Panel 1 and E140 where abnormal convergence rates and/or roof deformation rates have been measured. Factors that are known to influence the results are also noted in Table 1.

Based on observations of roof appearance and lateral offset in boreholes (Table 3), we suspect that the first roof beam (between clays G and H) has fractured, forming a cantilever beam in Panel 1 and the E140 drift. When a cantilever beam is formed, lateral movements may increase toward one side of an opening, inducing high bending moments along bolt shanks. A recent study (Peterson 1995) suggests that typical 3/4-in. in diameter, 10-ft-long, mechanically anchored, grade-75 bolts can stretch 8 in longitudinally prior to failing but could accommodate 1.5 in of lateral offset loading.

Table 1. Rate of roof deformation for selected areas

Location	Maximum yearly rate, in/yr	Current rate, in/yr	Comment
Room 1, Panel 1-center-north	1.15	1.3-1.5	Movements are influenced by detensioning procedures.
Room 4, Panel 1-north	1.5	1.1	Supplementary support has been installed, reducing rate.
Room 5, Panel 1-north	1.15	0.7	As above.
Room 6, Panel 1-center	1.06	1	
E140-S1300 to S1950	1.30-1.60	NA	Roof beam being mined.

Table 2. Roof-floor convergence rate for selected areas, inches per year

Location	Predicted*	Current	Percent difference
Room 1, Panel 1	2.05	1.9 to 4.8	-7 to 134
Room 3, Panel 1	2.1	2.7	28
Room 4, Panel 1	2.15	2.6	21
Room 5, Panel 1	2.15	2.5	16
Room 6, Panel 1	2.15	3.2	49
Room 7, Panel 1	2.15	2.1 to 3	0 to 39
E140,S1300 - S1950	1.74	1.7 to 4.5	0 to 158

* DOE/WIPP-95-2100 — Equations are updated by the operator on a routine basis.

This study also suggests that bolt life can be increased by reducing tension in the bolts to below 20,000 lb. This is the logic for detensioning point-anchored, threaded rebar in Room 1.

In spite of detensioning, however, there have been four reported point-anchored, threaded rebar failures in Room 1. These failures have occurred near the middle (mid-pillar) of the room where the lateral offset rate is maximum (0.7 in. in 1 year). Bolt failure not only depends on bolt load, lateral offset, and bolt grade, but also on installation practices, environmental factors, rates of ground movement, and fatigue; the latter is important where cyclic loading of bolts is involved (such as in Room 1, Panel 1). Considering the large increase in the number of bolt failures in the E140 entry with time, we suspect there will be an increase in the number of bolt failures in Panel 1 during the planned life of this panel. Remedial measures have been initiated and need to be expanded to minimize any safety problems associated with failures of roof bolts.

Table 3. Roof beam offset at or below clay G and observed roof fracturing.

Location	Offset, in	Shear fracture	Tensile fracture	Comment
Room 1-center	2.5	Yes	No	Near threaded rebar failure locations.
Room 3	1.5	Yes	No	
Room 4, north	3	Yes	Yes	Cantilever forming.
Room 5, center-north	3	Yes	Yes	As above.
Room 6, center-north	3	Yes	Yes	As above.
Room 7, north	2.5	Yes	Yes	As above.
S1600, Room 2-6	NA	Yes	No	
E140, S1000-S1300	NA	Yes	No	
E140, N150-N1400	NA	Yes	Yes (locally)	Local cantilevers forming.

In summary, the immediate roof beam is gradually breaking up along portions of the E140 drift and Panel 1. In response to these changes the operator has developed an Annual Ground Control Operating Plan to assess roof conditions systematically and provide a means of installing supplementary support to minimize the potential for roof falls. In addition, we observed some remedial measures in Room 1, Panel 1, to help reduce safety problems associated with falls of threaded rebar (Figure 7); these remedial measures need to be expanded to include all types of bolt fixtures.

2.2 Rib and Floor Stability

Lateral rib movements are very gradual and small, averaging about 0.7 in/yr. Rib movement depends on excavation height, among other factors, and thus higher entries require more attention. A great majority of tall ribs have been supported by wire mesh and rock bolts, and thus there is little potential for falls and resultant injuries.

According to site-specific equations, the rate of rib movement should decrease in time. An examination of extensometer data, however, indicates an exception to this pattern is occurring in Rooms 5, 6, and 1, Panel 1, i.e., the rate of rib movement has slightly increased. Although this slight increase is not a safety concern at this time, it may be indicative of (1) malfunctioning instruments, (2) initiation of tertiary creep within the pillars, (3) development of inelastic zones in the mine roof and/or floor, (4) unfavorable local geologic conditions, and/or (5) increased pillar loading due to load transfer from adjacent excavations, including the mains. The latter is analyzed below.

Load transfer from the mains toward Panel 1 can be visualized by analyzing changes in stress distribution over time using a preliminary displacement-discontinuity model. Attachment A presents the vertical stress distribution over the mains using program Exparea (St. John 1978; St. John and Maleki 1991). In these plots, squares are 7- by 7-ft salt elements, the color of which depends on the vertical stresses acting on them. Three years after excavation of the mains, vertical stresses decreased near the entries, spread over the pillars, and were transferred toward the sides. Such load transfer mechanisms commonly create roof stability problems in adjacent entries in evaporite mines if the isolating barrier pillars are not large enough. Note that a similar process can occur after Panel 1 is mined (not modeled). Loads are transferred back toward the mains. Such load transfer can increase floor heave, cause lateral movements within the roof beam, and contribute to fracturing of the roof beam in wide (>20 ft) entries.

Floor movements have also been gradual and do not pose any immediate stability-related safety concerns. Frequent milling of the floor, however, changes the width-to-height ratio of the entry and may affect long-term rib and roof movement.

3.0 ANTICIPATED CONDITIONS

The technical approach for estimating ground conditions during the active life of Panel 1 and E140 consists of developing a mathematical relationship between the convergence rate and several mining, support, and time factors, and then using these relationships to calculate total expected convergence at these locations. After a brief review of the analysis technique, we identify important variables and estimate future deformation and ground conditions while examining some of the assumptions inherent in these analyses.

3.1 Analysis Technique

Multilinear regression analysis techniques are used as a tool to help predict ground movements during the active life of Panel 1 (until 2004) and the E140 drift (until 2035). To assess both roof and floor conditions, we have used closure rate as the independent variable, utilizing rates from both 1993 and 1994 (Westinghouse 1995; USDOI 1994) and the last available data (Figure 5). Dependant variables were selected on the basis of underground observations, data analysis, and preliminary bivariable correlations.

- *Roof span.* Measured roof-floor convergence depends on roof span, which varies between 11 to 33 ft; attachment B presents statistics.

- *Roof beam thickness.* This variable measures the distance between the roof and clay G or H, depending on the relative position of the entry with respect to such clays (range 4 to 12).

- *Entry height.* Height generally varies between 8 and 15 ft and reaches 18 to 20 ft in room D and the salt handling shaft station. The latter (tallest) entries are located in isolated areas far away from multiple-room panels.

- *Age.* Time from excavation year to present.

- *Excavation ratio.* This variable relates to higher vertical stresses, which are associated with higher overall extraction in any certain area.

- *Bolt length.* Roof bolts vary in length from 1 to 13 ft.

- *Bolt spacing.* This variable relates to the density of roof bolts.

The multilinear regression procedure consisted of entering the dependant variables one at a time into the equation using a forward selection methodology. In this method, a variable is entered into the equation using the largest correlation with the dependant variable. If a variable fails to meet entry requirements, it is not included in the equation. If it does meet the criteria, the second variable with the highest partial correlation will be selected and tested for entering into the equation. This procedure is very desirable when there are hidden relationships among the variables. Attachment C presents the output and selected plots for checking the validity of a linear regression analysis. Coefficient of determination for the last step (5) is 0.63; R_2 is a measure of goodness-of-fit.

3.2 Important Variables

Based on an examination of standardized regression coefficients, the following variables best explain variations in the convergence rate.

- *Excavation ratio.* The convergence rate is higher as the excavation ratio (and the associated vertical stresses) increases.

- *Span.* Increasing the span results in an increase in convergence rate.

- *Beam thickness.* The thicker the roof beam, the lower the convergence rate.

- *Entry height.* Convergence rate is negatively related to entry height.

- *Age.* Convergence rate increases slightly as entries age.

It is very interesting that bolting parameters (bolt density and bolt length) do not add significantly to the goodness-of-fit and thus are not included in the final equation.

3.3 Expected Ground Conditions — Panel 1

Having developed a relationship among convergence rate, mining, and time variables, total roof-floor convergence can be calculated for both E140 and Panel 1. For this, we have used average measured convergences using 1995 as the base and have added expected convergence for the anticipated life of the entries (Figure 8). The calculated difference in movements for Room 1 and 7 is due solely to age differences, because other analyzed variables, such as bolting parameters, were found to be insignificant. In reality, the special support system in Room 1 provides some safety advantages in the short term, but these advantages can be expected to become ineffective before the turn of the century for the following reasons:

- Room 1 is closest to the main entries within its load transfer distance; it is experiencing the highest convergence rate at this time

- The effectiveness of both mechanical bolts and threaded rebar is expected to deteriorate because of high lateral offset, potential for fatigue failure caused by frequent detensioning (3 to 12 times per year), and short, unused lengths of pigtail (<6 in) for a number of bolts.

Total roof-floor convergence is expected to double in portions of Panel 1 during the active life of this panel. Assuming that the ratio of roof-to-floor movements will remain unchanged in the future, expected roof movements will also double during this period. Figure 8 presents estimated total convergence for Rooms 1 and 7.

The expected increase in convergence for each room depends upon the waste emplacement schedule and sequence. Table 4 presents increases in convergence for one sequence of waste emplacement specified by EEG. There is a very significant increase (55% to 101%) in expected roof and floor movements during years 2001 to 2004 while Rooms 3 to 7 are filled. Considering the fractured nature of the mine roof and the expected additional deformation, there will be a need for additional, systematic internal and external support systems (such as cribs); the latter reduce storage capacity but will be very important for maintaining stability, particularly during the 1-year period of actual waste placement when it may not be possible to install additional support or to detention threaded rebar.

Table 4. Percentage of increase in roof-floor convergence during the anticipated life of Panel 1

Year	Waste placement sequence	Percent increase
1998	Room 1	33
1999	Room 2	44
2000	Room 3	55
2001	Room 4	66
2002	Room 5	77
2003	Room 6	89
2004	Room 7	101

Table 4 may also be used to estimate an increase in floor movement, assuming that the ratio of roof- to-floor movement will remain constant. Floor movements are of less safety concern; however, frequent milling of the floor to provide storage space may accelerate nonlinear behavior in the mine pillars and/or floor, further accelerating roof movement beyond the projected levels. Numerical modeling may be used to analyze such effects in order to improve the accuracy of these projections.

3.4 Expected Ground Conditions — E140

The regression equation was used to estimate total roof-floor convergence in E140 for the remaining life of these entries. Figure 9 presents results for two typical conditions where the immediate 5-ft beam is in place and at locations where the immediate beam is removed (a 20-ft-high and 6.5-ft-thick beam directly above clay G).

Total roof-floor movement is projected to increase by a factor of 5 to 6 during the next 40 years. Such a significant increase in convergence will require frequent maintenance, which may involve adding supplementary support, replacing failed bolts, removing roof beams, milling the floor, and trimming the ribs. Mining the ribs and floor increases the effective span and extraction ratio and thus may accelerate nonlinear movement in the pillars and in the floor, creating new challenges for maintaining equipment clearance and stability requirements.

3.5 Discussion of Results and Assumptions of Analysis

Regression analysis is a powerful method for identifying important variables and for estimating conditions in the near future. Interpretation of the results, however, requires a good understanding of data structure, interrelations within the variables, and the mechanics of time-dependant deformation. Here are a few comments relating to the interpretation of results and improving future models.

- Several mining parameters are shown to have a significant impact upon the convergence rate, including span, extraction ratio, beam thickness, and height. Several other parameters, such as excavation sequence, load-transfer distances, and excavation orientation with respect to the stress field, are not included in the present analysis and can improve the goodness-of-fit.

- Although the existing database is generally broad (119 data points), data structure and missing variables at some locations influence the results. For instance, the negative multiple correlation of convergence with height is influenced by short-term measurements at such locations as the salt shaft station, where the removal of the immediate roof beam has reduced the convergence rate of this isolated location (see photo on report cover). Results could be different when additional data are included pertaining to locations influenced by load transfer from the panels.

- The assumption provided by the linear regression analysis is valid for the range of analyzed convergence rates (1994-1996). Future nonlinear acceleration in deformation resulting from tertiary creep or deceleration in deformation will require additional nonlinear analyses for future evaluations.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on underground observations, data analysis, modeling and professional judgment, we have come to the following conclusions:

- There are two types of events that can contribute to stability-related safety concerns during the active life of Panel 1 and E140: (1) Free fall of failed roof bolts and (2) localized roof falls. The first type has a high probability of occurrence, but damage would be less severe, while the second type has a lower probability of occurrence, but damage would be more severe. Other types of failure, such as catastrophic failure, have low probabilities of occurrence and may best be addressed through additional modeling and a failure mode analysis approach. Excluded from this stability evaluation are procedures used for safely removing the immediate roof beam and an evaluation of ground stability as a result of dynamic and thermal loading, if any.

- The potential for roof bolts to fail and fall is high, considering environmental conditions, installation practices, and expected future deformation. Safety problems associated with bolt falls, however, can be controlled by either connecting the bolt assembly to the roof or putting another layer of mesh over the bolts to prevent failed bolts from falling.

- The potential for the formation of roof slabs and localized cantilever beams in the mine roof is high, considering both the present condition of the roof and anticipated deformation. Roof fall potential is judged to be low as long as access is available and supplementary support is installed in a timely fashion. The presence of an extensive monitoring system, trained geotechnical staff, systematic roof assessment procedures, and the availability of funds are very favorable factors that would help the operator to prevent roof falls.

- The potential for localized roof beams to collapse and create safety hazards during waste emplacement operations can further be reduced by using external support systems, such as cribs, and/or abandoning some unstable rooms.

To "assure stability" and safety, it is best to abandon Panel 1 and mine a new panel as soon as all permitting processes are complete. The new panel should be positioned at a sufficient distance from Panel 1 to minimize the detrimental effects associated with load transfer from Panel 1 toward the new panel. To improve the long-term stability of E140, it is important to modify the excavation geometry and possibly to increase barrier pillar widths for future entries and panels.

With a high degree of confidence, it would be possible to safely use portions of Panel 1 for waste storage. This would require close monitoring and periodic stability assessments to identify the most stable rooms. In addition, we foresee the need for installation of external support systems to prevent the potential for roof falls during waste emplacement operations.

5.0 REFERENCES

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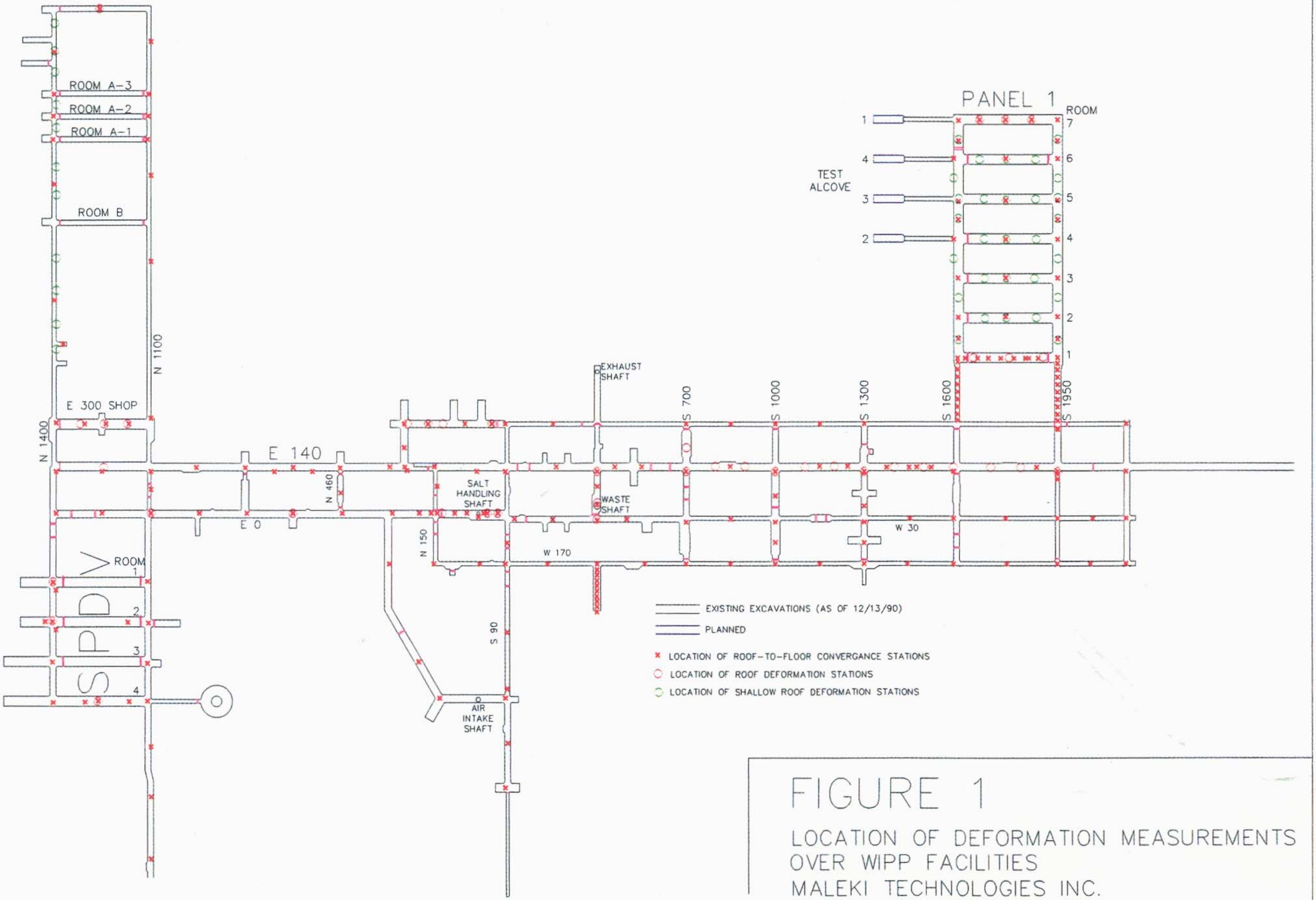


FIGURE 1

LOCATION OF DEFORMATION MEASUREMENTS
OVER WIPP FACILITIES
MALEKI TECHNOLOGIES INC.

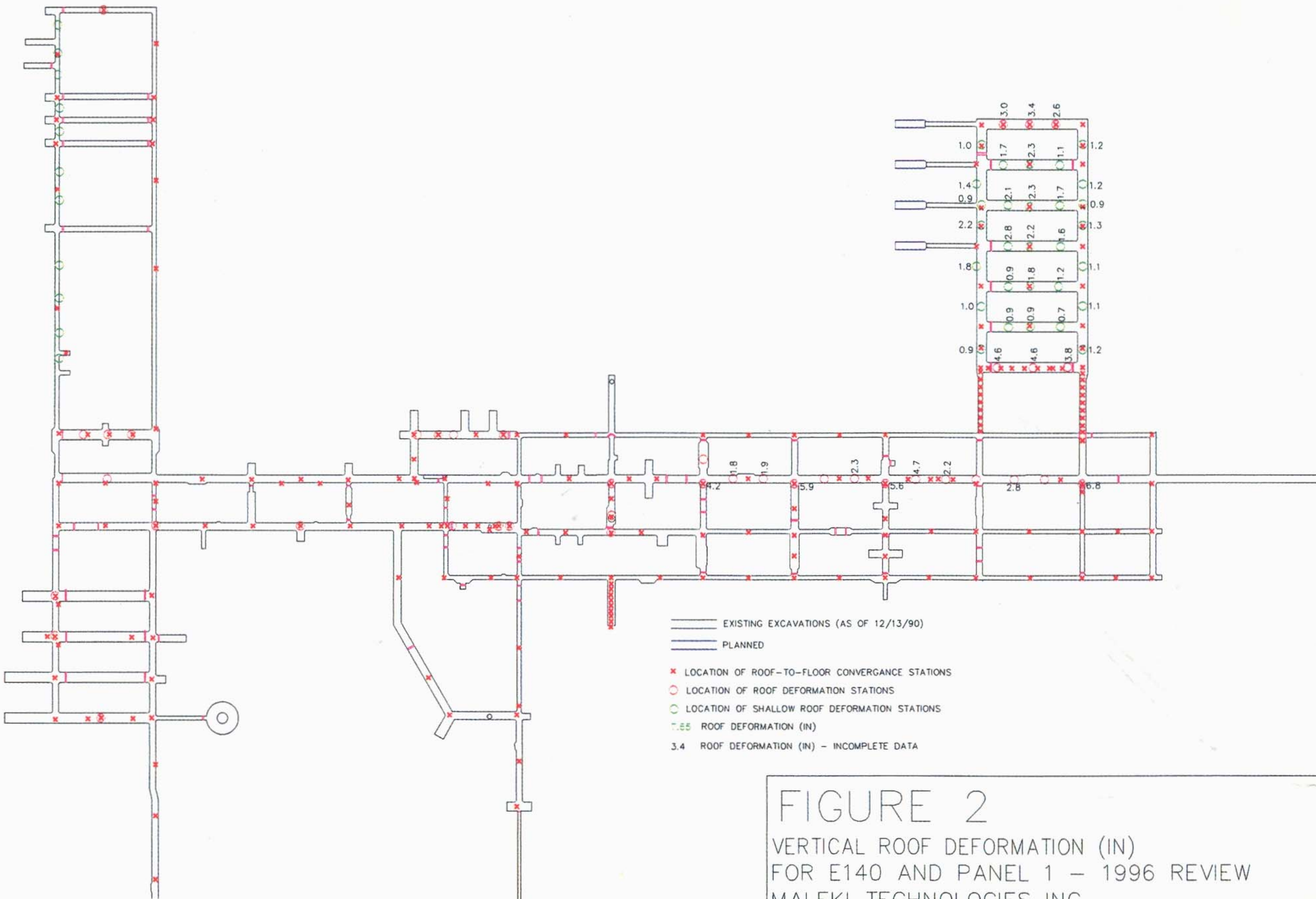


FIGURE 2

VERTICAL ROOF DEFORMATION (IN)
FOR E140 AND PANEL 1 - 1996 REVIEW
MALEKI TECHNOLOGIES INC.

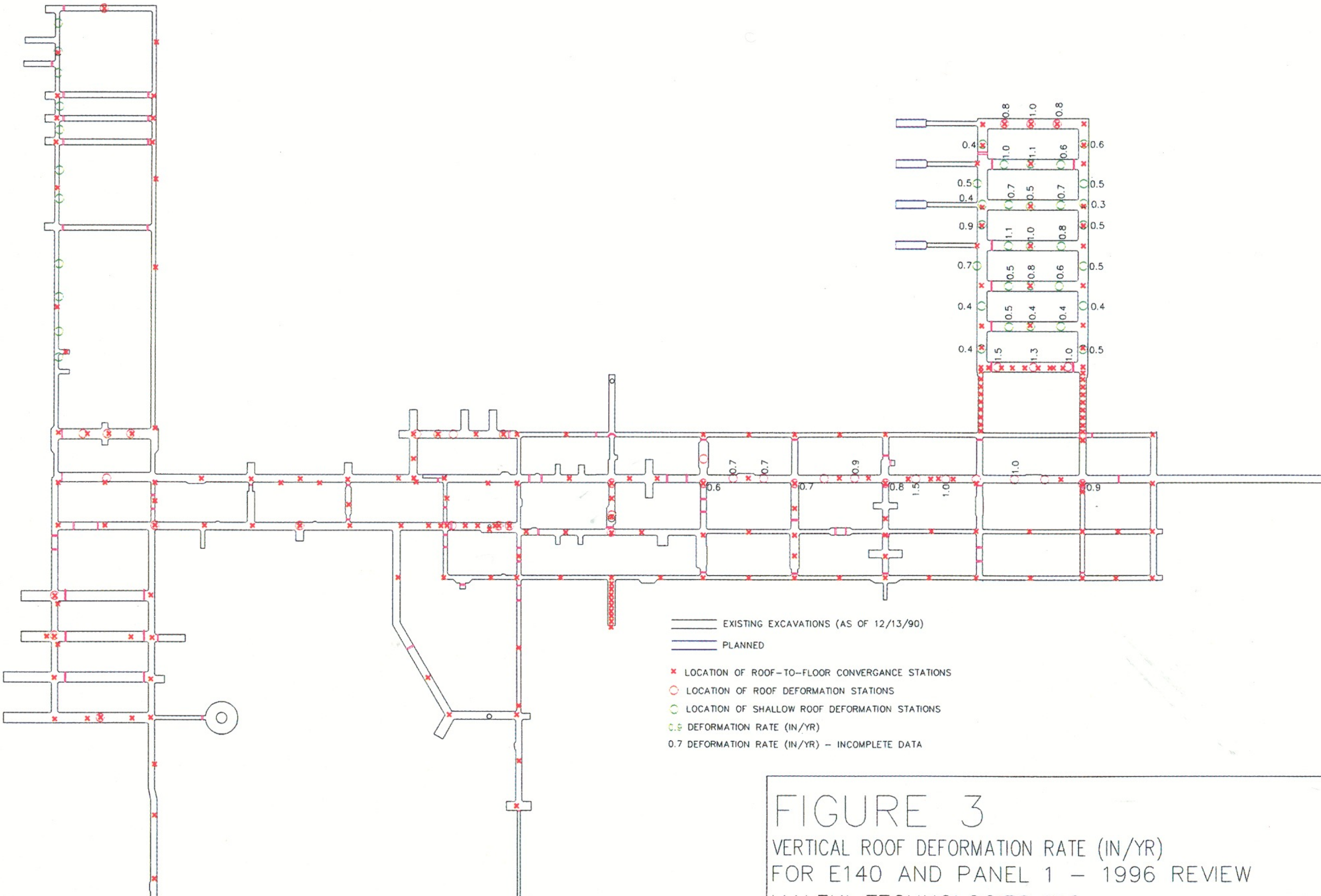


FIGURE 3
VERTICAL ROOF DEFORMATION RATE (IN/YR)
FOR E140 AND PANEL 1 - 1996 REVIEW
MALEKI TECHNOLOGIES INC.

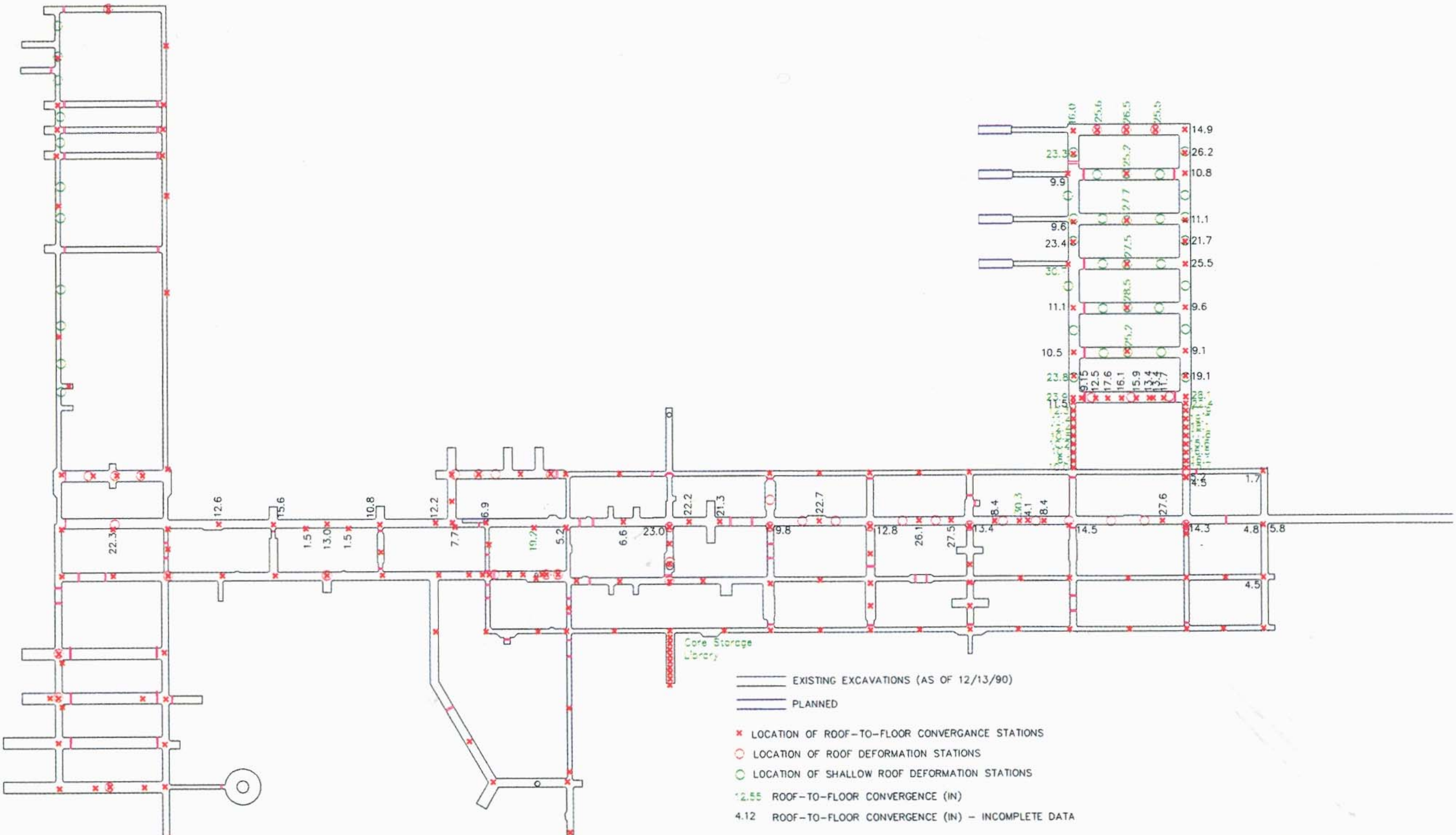


FIGURE 4

ROOF-TO-FLOOR CONVERGENCE (IN)
FOR E140 AND PANEL 1 - 1996 REVIEW
MALEKI TECHNOLOGIES INC.

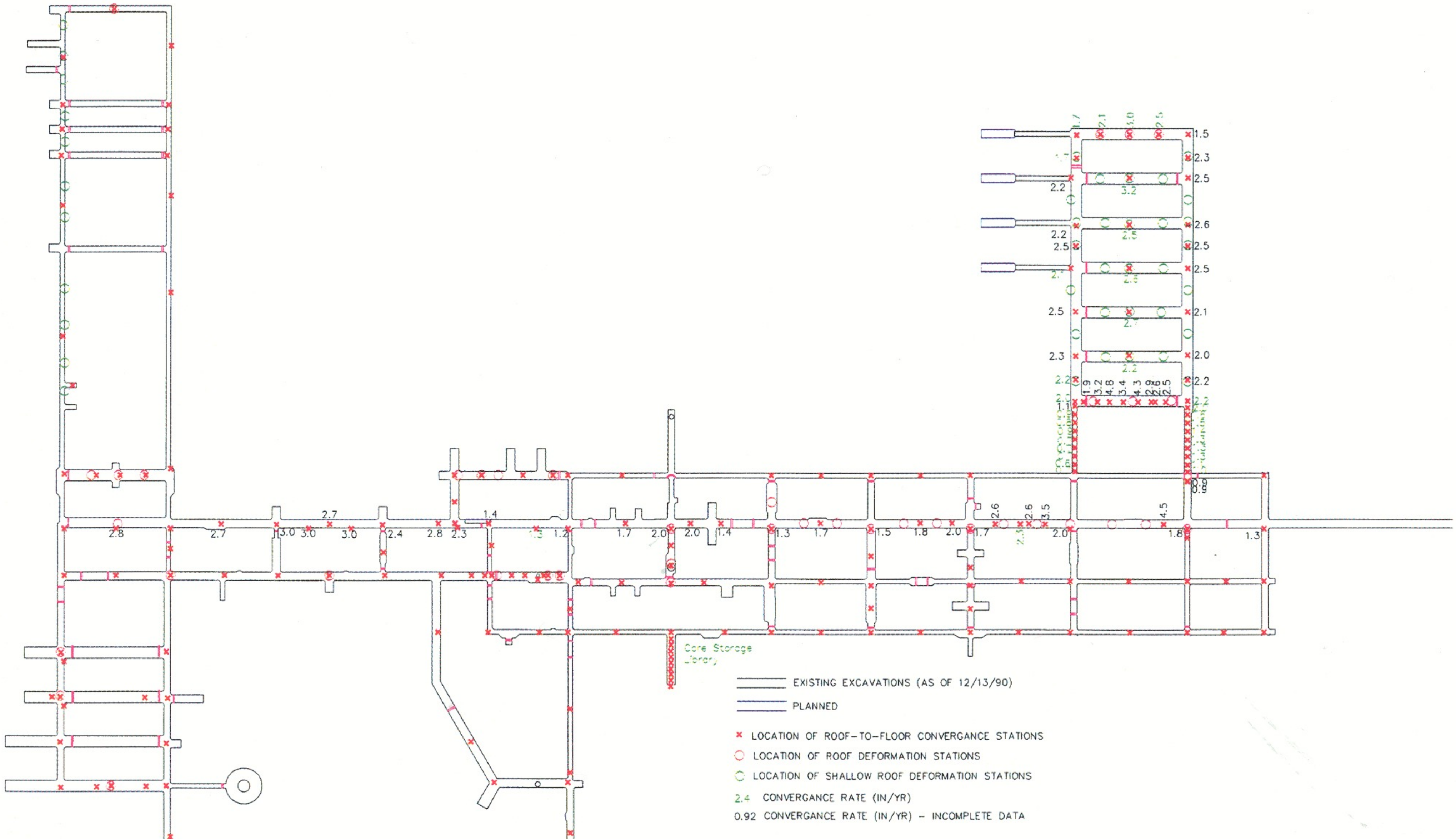


FIGURE 5

ROOF-TO-FLOOR CONVERGENCE RATE (IN/YR)
FOR E140 AND PANEL 1 - 1996 REVIEW
MALEKI TECHNOLOGIES INC.

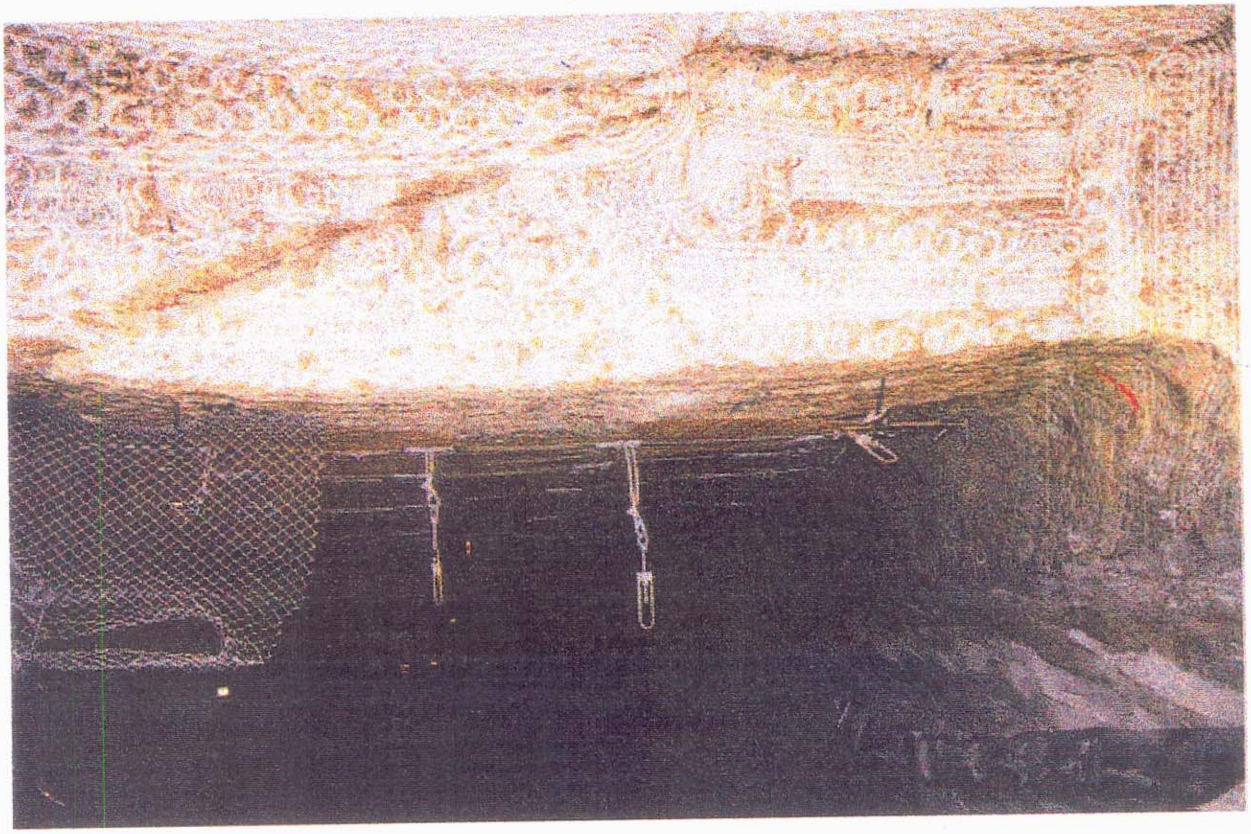


Figure 6 - The immediate roof beam and the fracture pattern at one location along E140 drift.

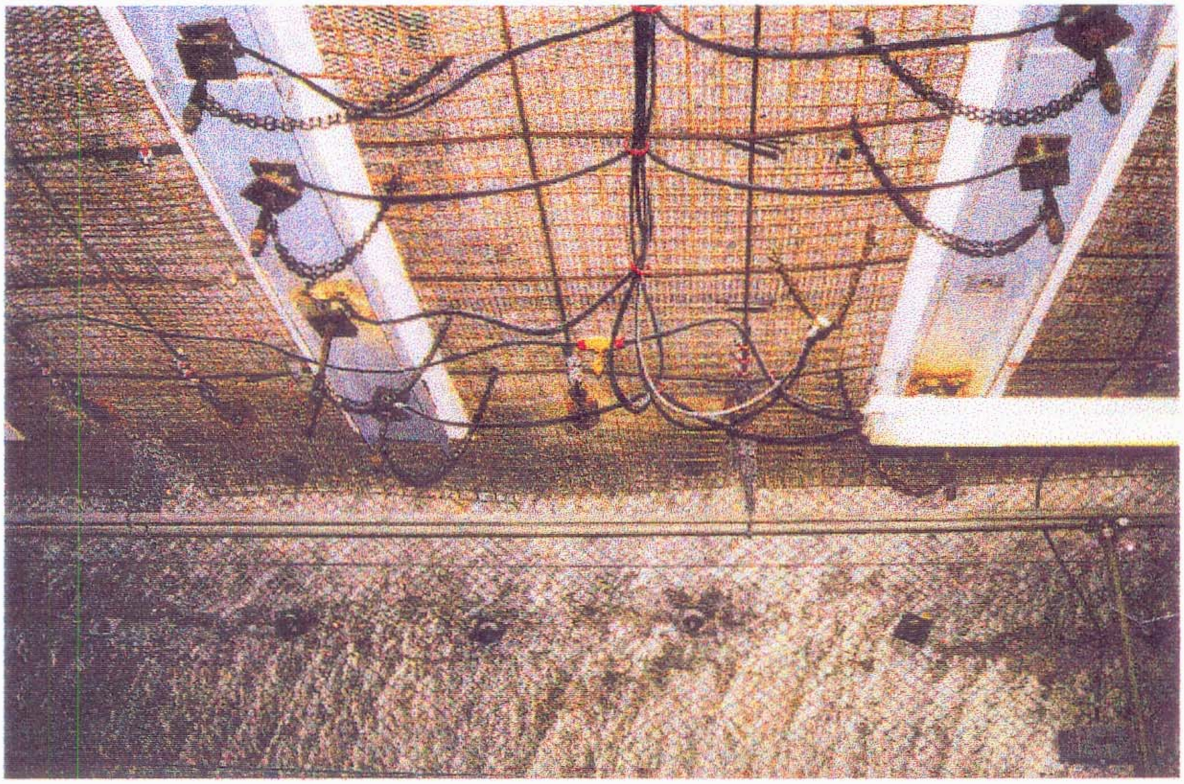


Figure 7 - Room 1, Panel 1 support system. Steel chain is used to prevent the potential for free fall of threaded rebars in the future.

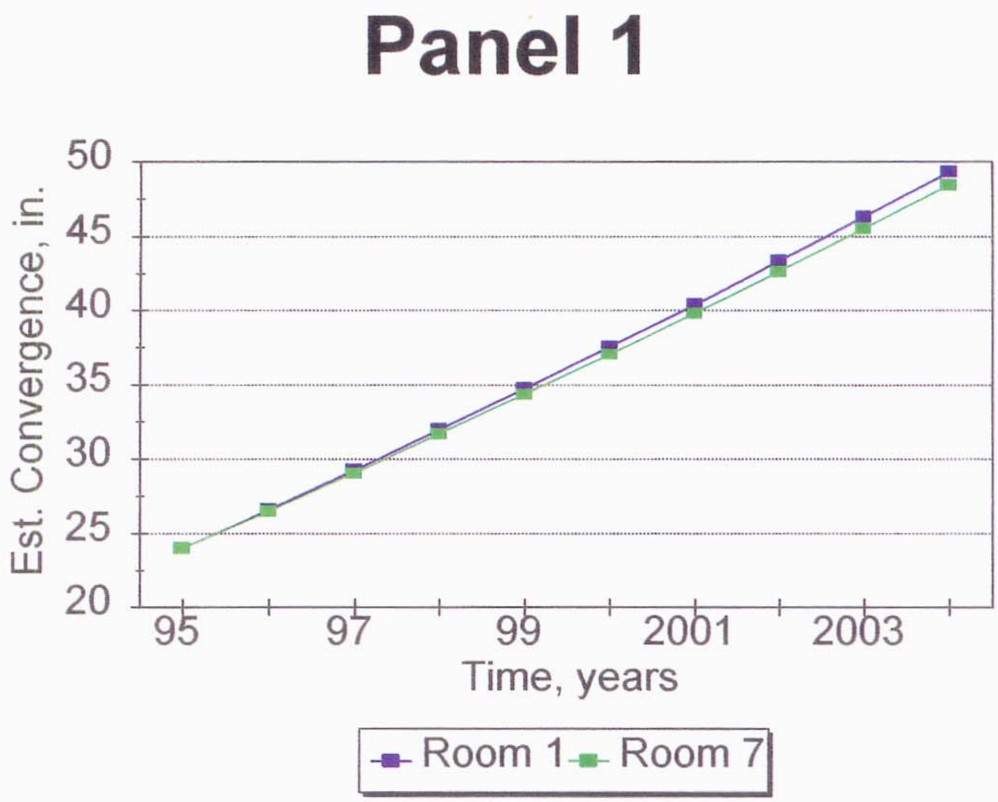


Figure 8 - Estimated roof-floor convergence for two rooms of Panel 1.

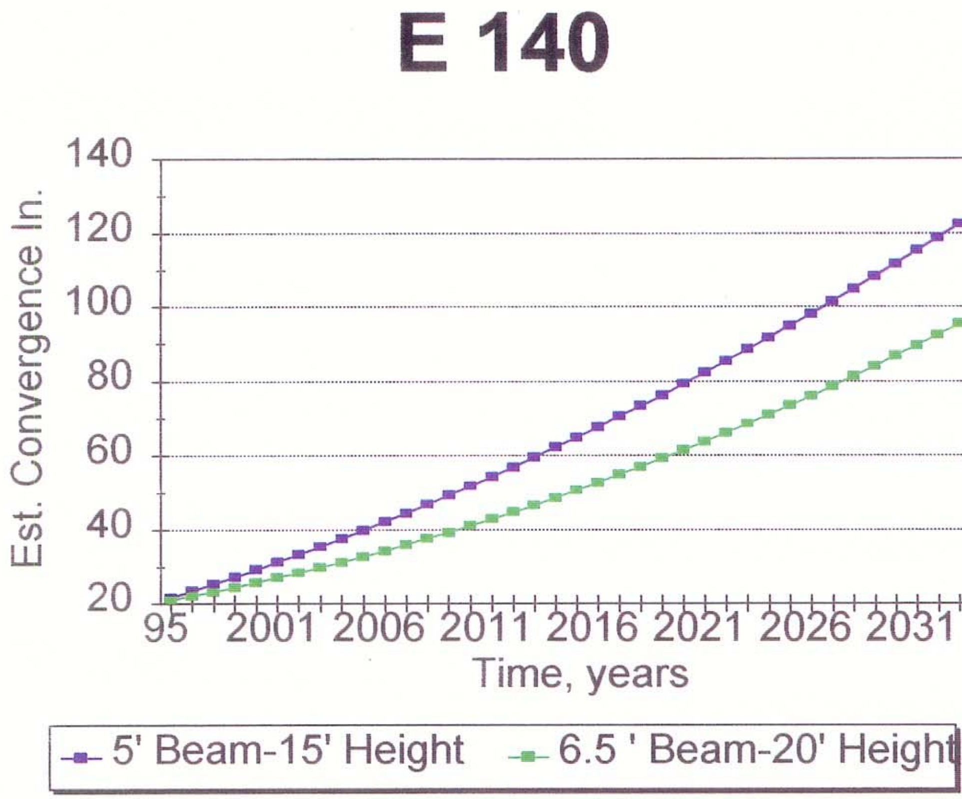


Figure 9 - Estimated convergence for E140 drift.

APPENDIX A

PRELIMINARY
STRESS ANALYSIS OF THE MAINS

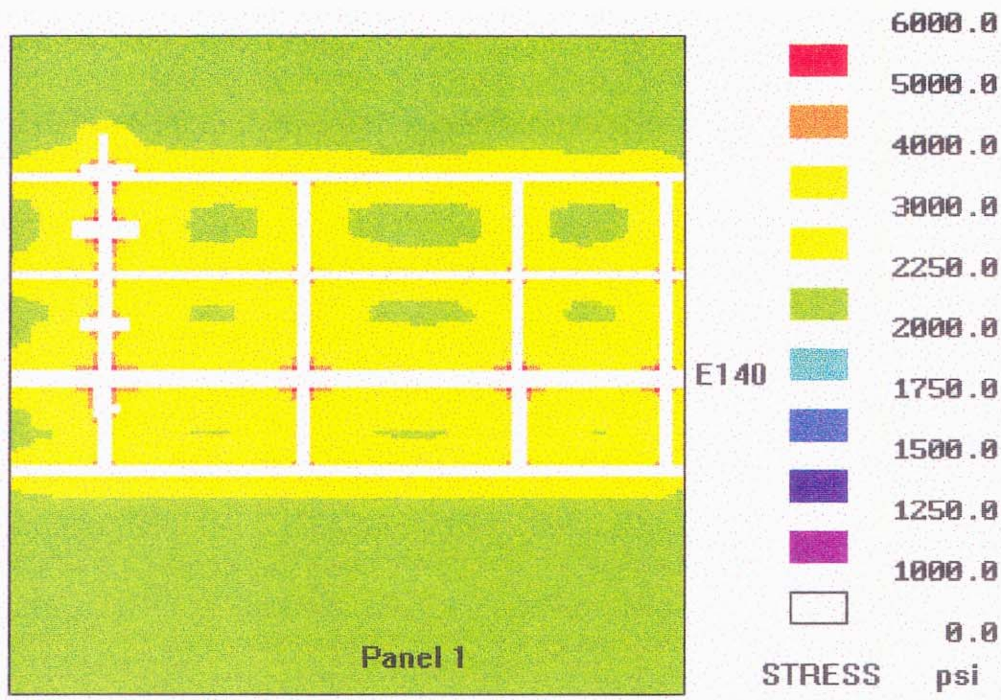


Figure A1 - Mining geometry and vertical stress levels at the time of mining.

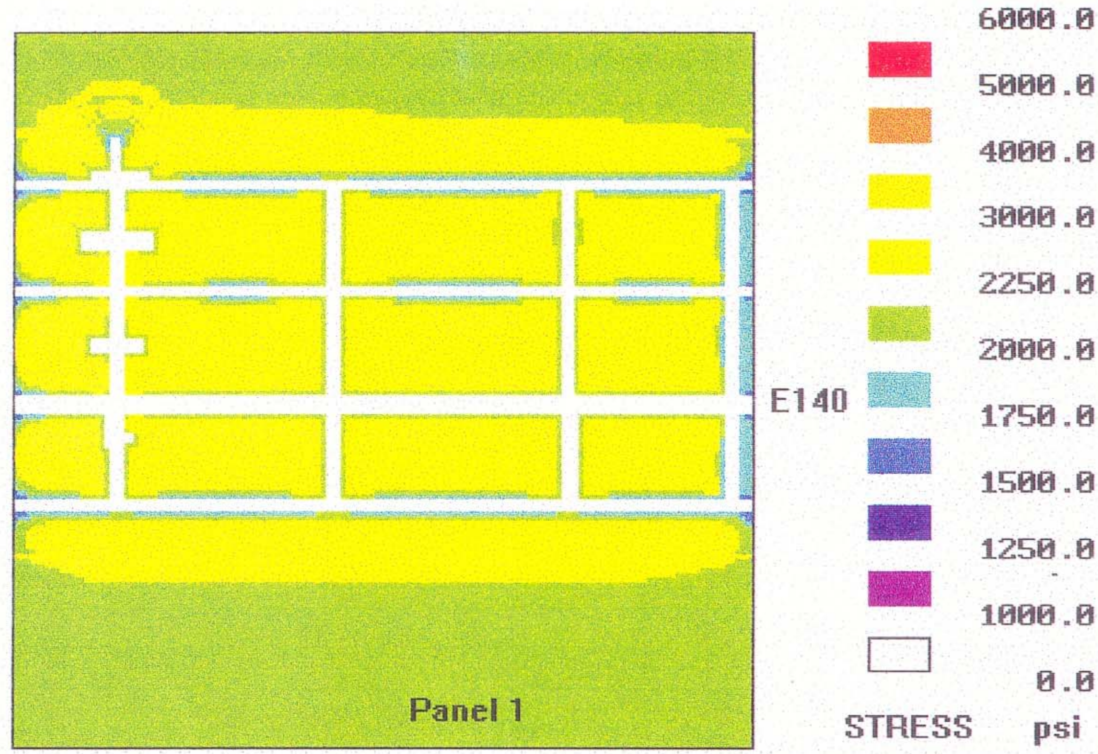
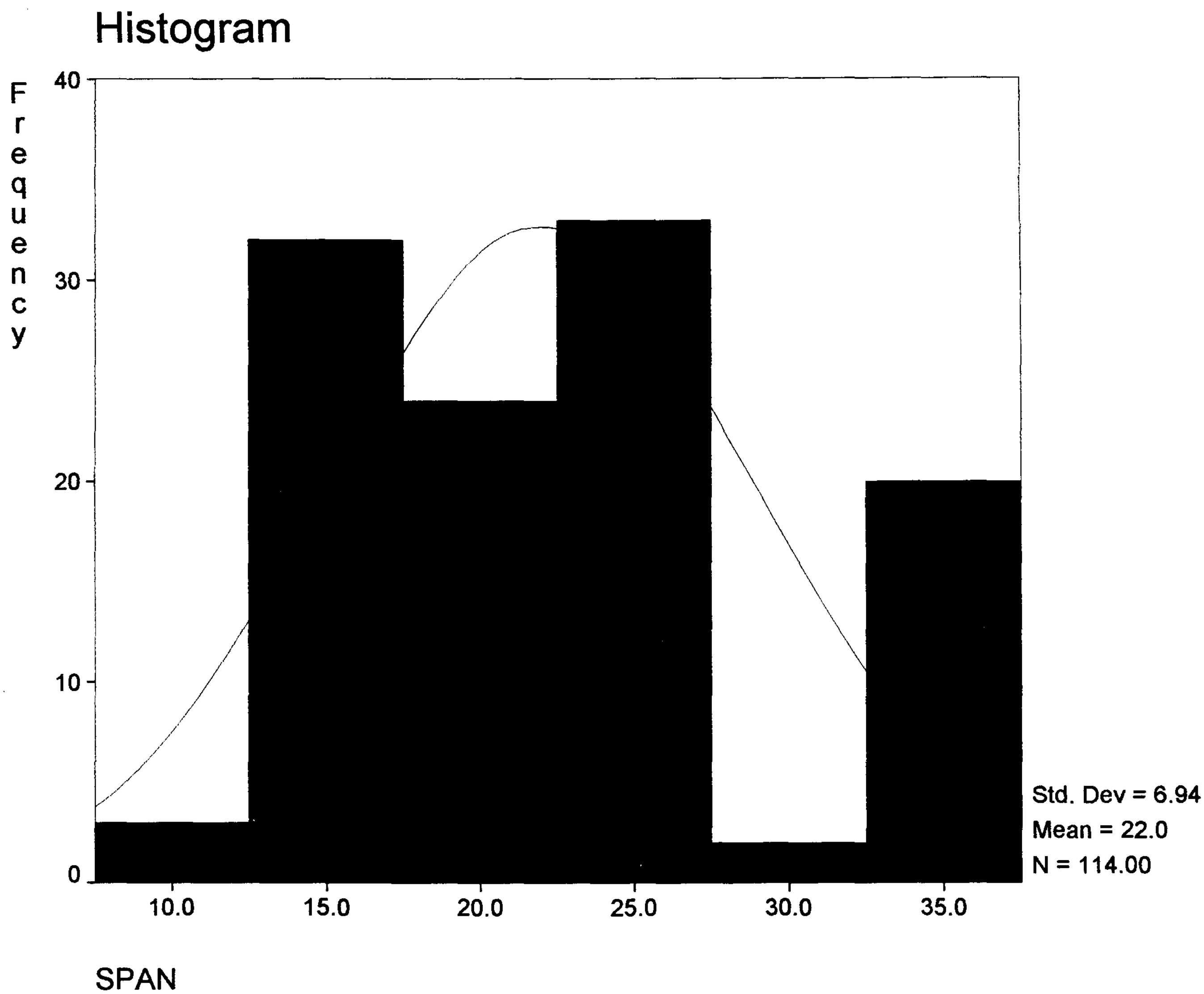


Figure A2- Mining geometry and vertical stress distribution three years after mining.

APPENDIX B

DATA STATISTICS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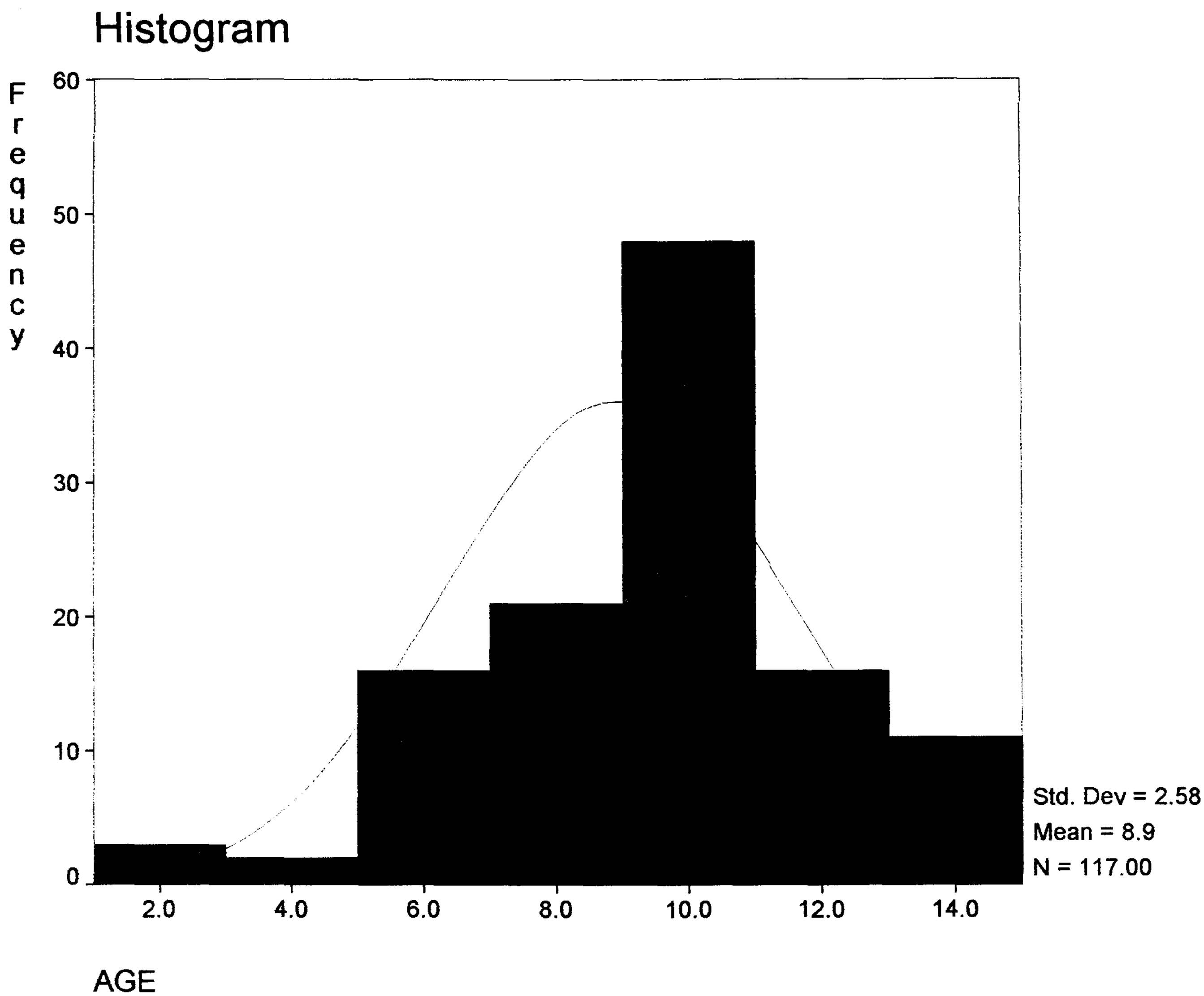
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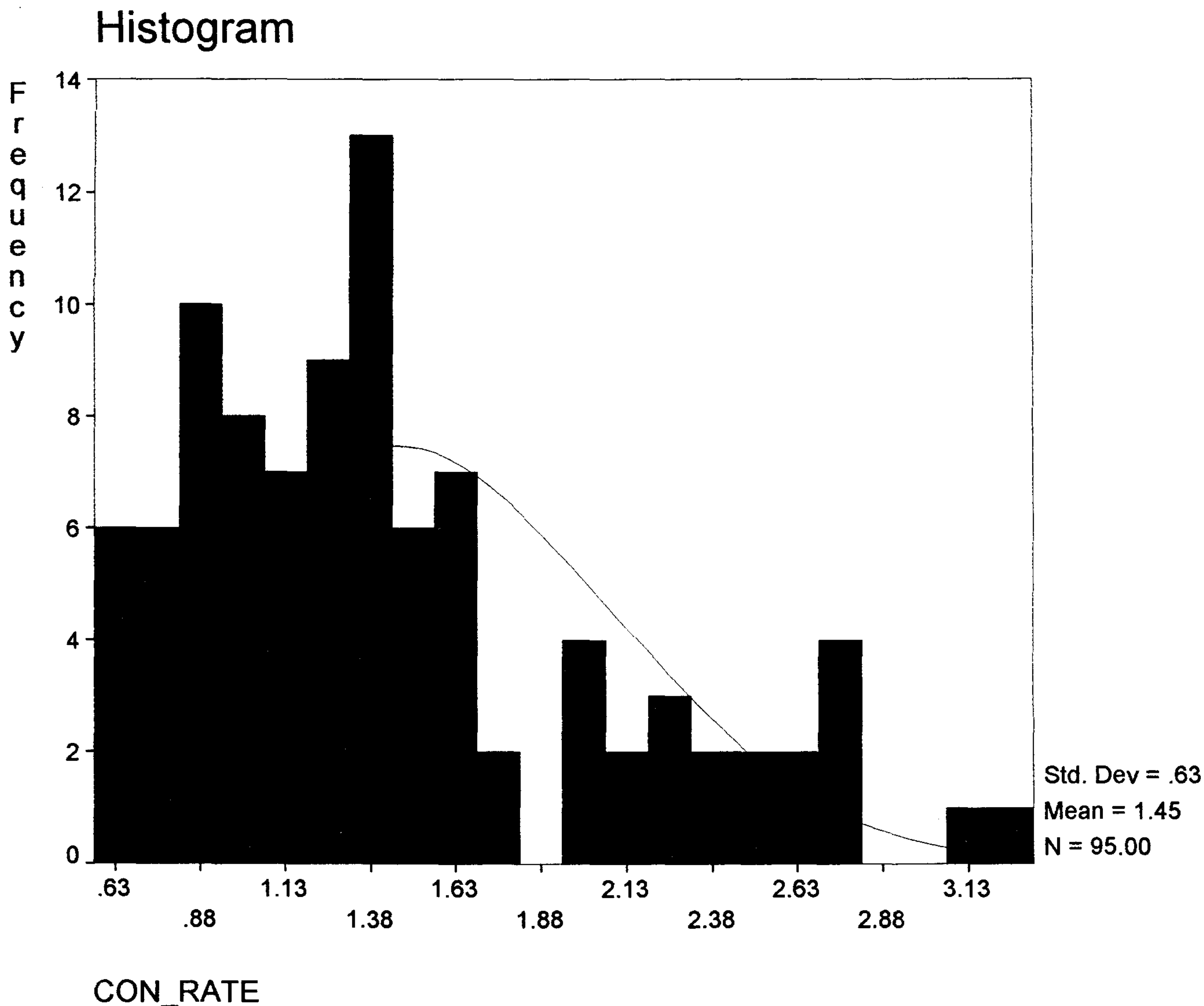
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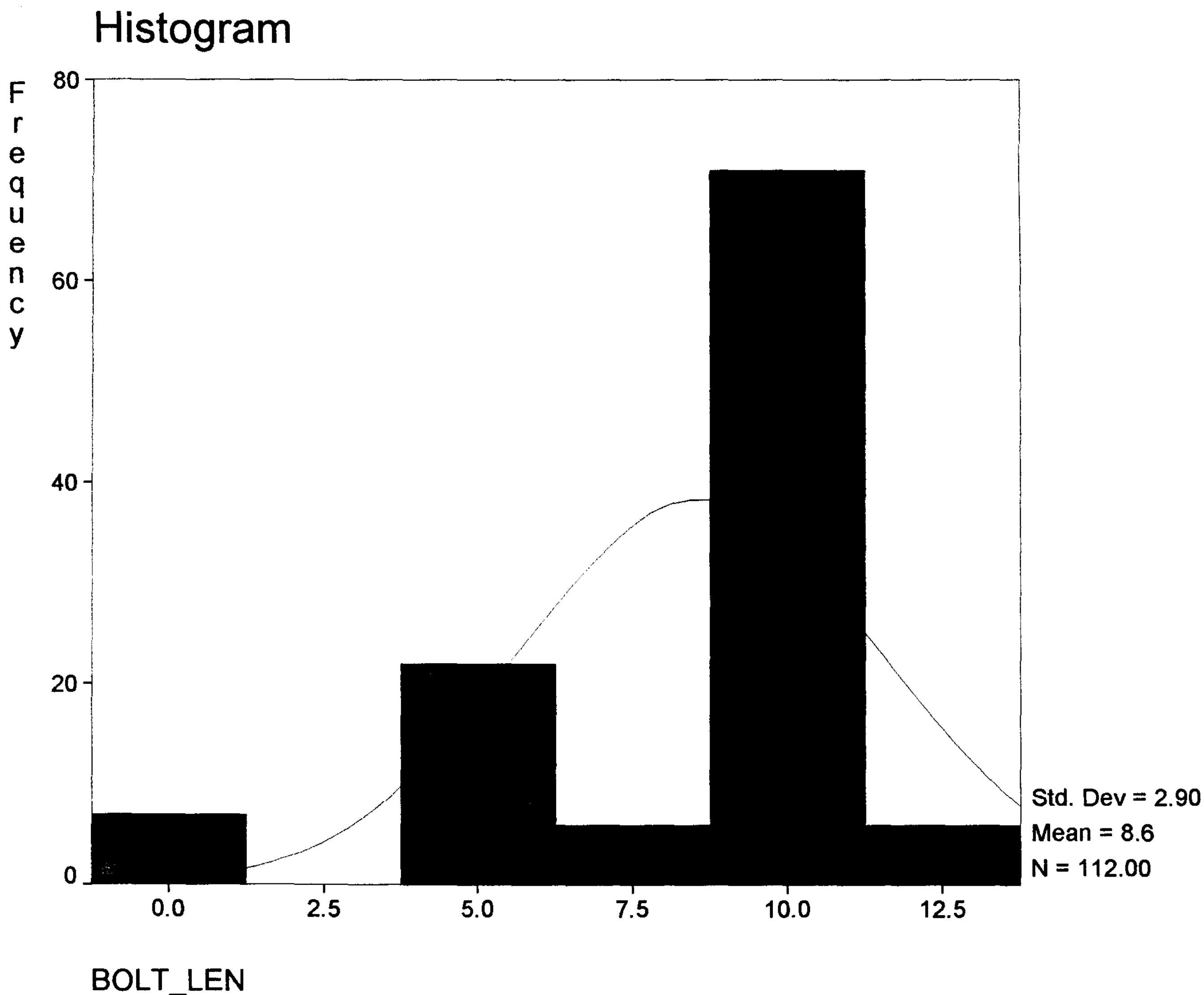

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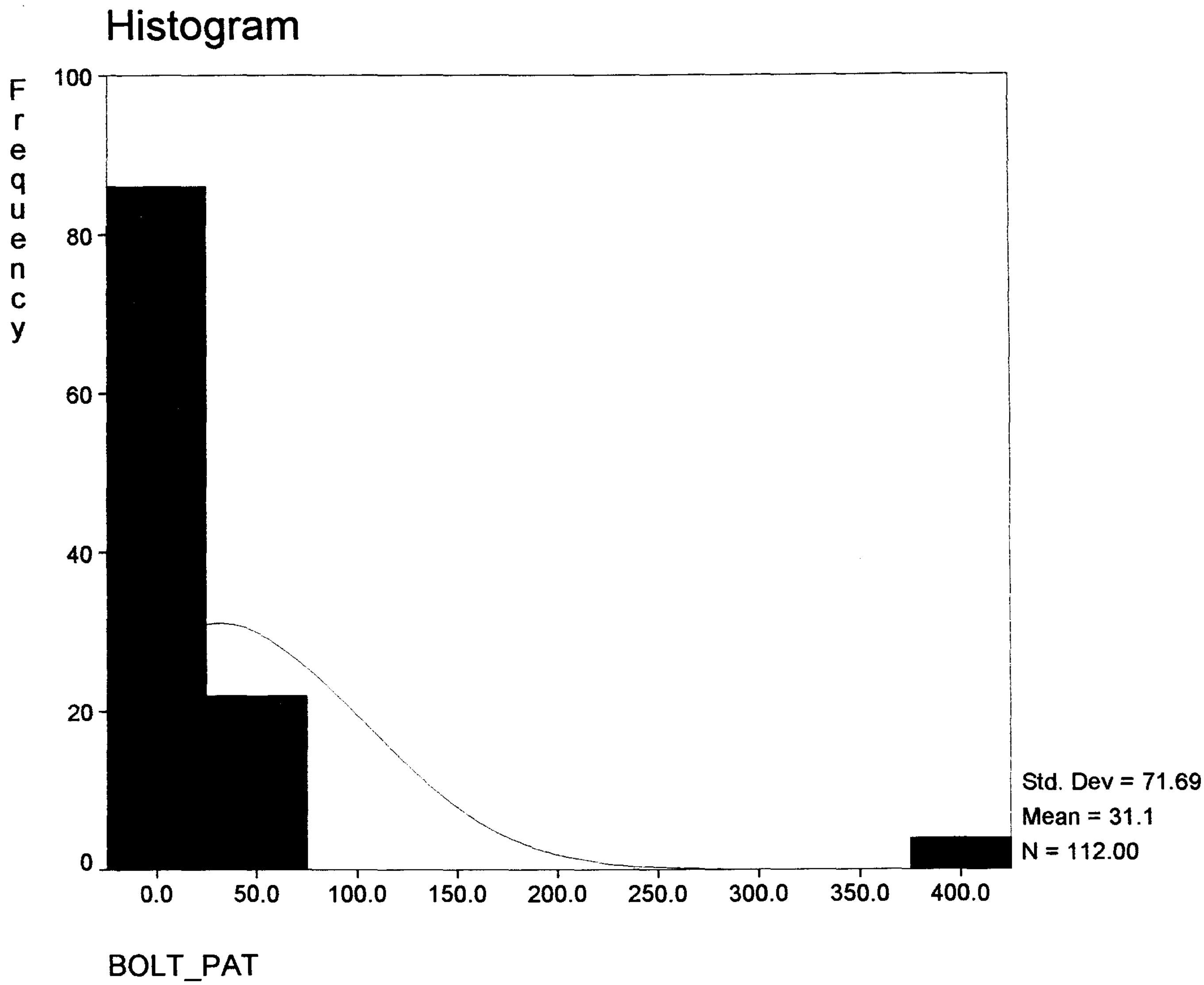
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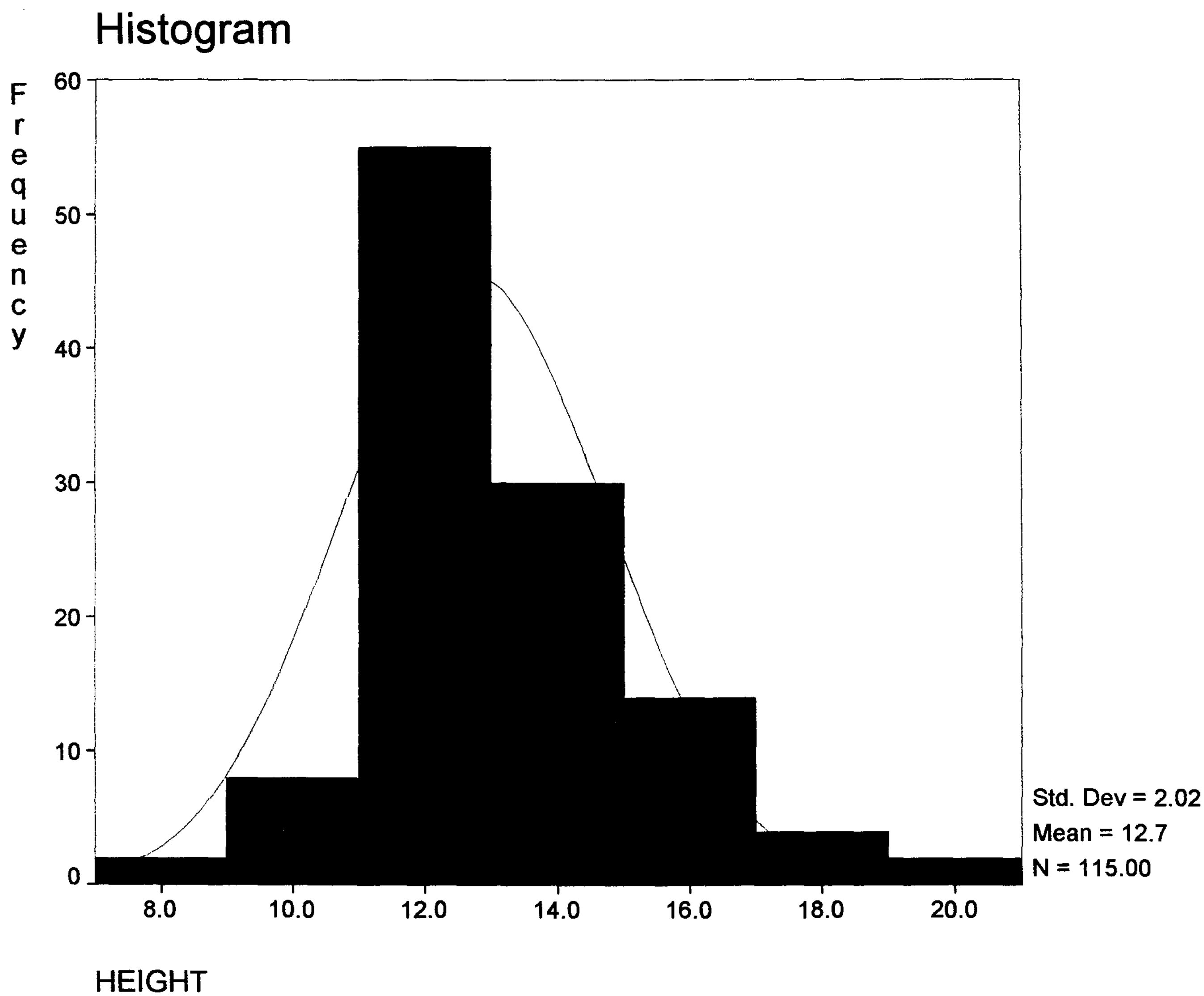
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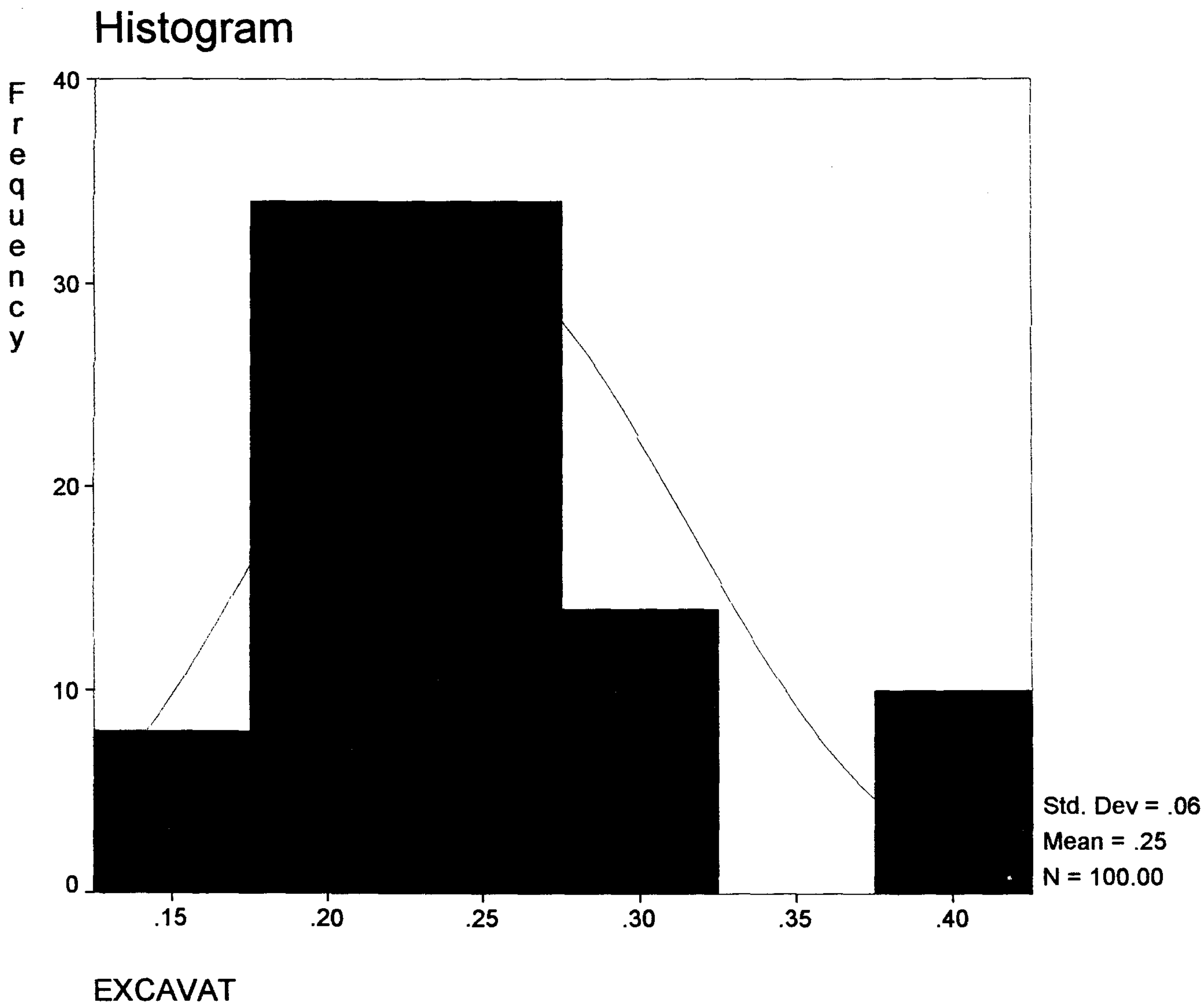
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Mean = .25
N = 100.00
EXCAVAT

APPENDIX C

REGRESSION ANALYSIS RESULTS

```
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Variable: SPAN       Type: Number   Format: F5
Variable: AGE        Type: Number   Format: F5
Variable: BEAM_TH    Type: Number   Format: F8
Variable: CON_RATE   Type: Number   Format: F8.2
Variable: BOLT_PAT   Type: Number   Format: F9.1
Variable: BOLT_LEN   Type: Number   Format: F9
Variable: EXCAVAT    Type: Number   Format: F8.3
Variable: ROOMXCUT   Type: Number   Format: F5.1
Variable: EXCA_SEQ   Type: Number   Format: F5


           * * * *   M U L T I P L E   R E G R E S S I O N   * * * *


Listwise Deletion of Missing Data

Equation Number 1    Dependent Variable..   CON_RATE

Block Number  1.  Method:  Stepwise    Criteria   PIN  .0500   POUT  .1000
   AGE      BEAM_TH  BOLT_LEN BOLT_PAT EXCAVAT  HEIGHT   SPAN


Variable(s) Entered on Step Number
   1..    SPAN


Multiple R           .69029
R Square             .47650
Adjusted R Square    .46961
Standard Error       .45880

Analysis of Variance
                    DF      Sum of Squares      Mean Square
Regression           1            14.56158         14.56158
Residual            76            15.99769           .21050

F =       69.17748       Signif F =  .0000


------------------ Variables in the Equation ------------------

Variable              B         SE B        Beta          T  Sig T

SPAN           .064527      .007758     .690292      8.317  .0000
(Constant)     .068041      .174322                   .390  .6974


------------- Variables not in the Equation -------------

Variable     Beta In  Partial  Min Toler         T  Sig T

AGE          .143850  .196061    .972482     1.732  .0875
BEAM_TH    -.156673 -.208707    .928973    -1.848  .0685
BOLT_LEN     .089994  .123720    .989377     1.080  .2837
BOLT_PAT   -.036055 -.049689    .994266     -.431  .6678
```

EXCAVAT	.291763	.308560	.585507	2.809	.0063
HEIGHT	-.009603	-.011921	.806737	-.103	.9180

* * * * M U L T I P L E R E G R E S S I O N * * * *

Equation Number 1 Dependent Variable.. CON_RATE

Variable(s) Entered on Step Number
2.. EXCAVAT

Multiple R	.72550
R Square	.52634
Adjusted R Square	.51371
Standard Error	.43931

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	16.08471	8.04235
Residual	75	14.47456	.19299

F = 41.67149 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
SPAN	.046968	.009708	.502451	4.838	.0000
EXCAVAT	3.025368	1.076916	.291763	2.809	.0063
(Constant)	-.305482	.213401		-1.431	.1564

------------- Variables not in the Equation -------------

Variable	Beta In	Partial	Min Toler	T	Sig T
AGE	.215200	.298251	.536548	2.688	.0089
BEAM_TH	-.267430	-.351855	.483247	-3.234	.0018
BOLT_LEN	.011565	.015619	.511318	.134	.8935
BOLT_PAT	-.014339	-.020675	.576986	-.178	.8593
HEIGHT	.059231	.074627	.445037	.644	.5217

* * * * M U L T I P L E R E G R E S S I O N * * * *

Equation Number 1 Dependent Variable.. CON_RATE

Variable(s) Entered on Step Number
3.. BEAM_TH

Multiple R	.76484
R Square	.58498
Adjusted R Square	.56816
Standard Error	.41399

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	3	17.87669	5.95890
Residual	74	12.68258	.17139

F = 34.76881 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
SPAN	.033359	.010070	.356873	3.313	.0014
EXCAVAT	4.222148	1.080225	.407180	3.909	.0002
BEAM_TH	-.123549	.038209	-.267430	-3.234	.0018
(Constant)	.567176	.336563		1.685	.0962

------------- Variables not in the Equation -------------

Variable	Beta In	Partial	Min Toler	T	Sig T
AGE	.161102	.230703	.469051	2.026	.0464
BOLT_LEN	.065471	.092612	.475112	.795	.4294
BOLT_PAT	-.056126	-.085273	.482395	-.731	.4670
HEIGHT	-.231765	-.231656	.414626	-2.035	.0455

* * * * M U L T I P L E R E G R E S S I O N * * * *

Equation Number 1 Dependent Variable.. CON_RATE

Variable(s) Entered on Step Number
4.. HEIGHT

Multiple R	.77927
R Square	.60726
Adjusted R Square	.58574
Standard Error	.40548

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	18.55729	4.63932
Residual	73	12.00198	.16441

F = 28.21790 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
SPAN	.039589	.010327	.423511	3.833	.0003
EXCAVAT	4.151840	1.058578	.400399	3.922	.0002
BEAM_TH	-.192222	.050395	-.416075	-3.814	.0003
HEIGHT	-.084717	.041638	-.231765	-2.035	.0455
(Constant)	2.022693	.787672		2.568	.0123

------------- Variables not in the Equation -------------

Variable	Beta In	Partial	Min Toler	T	Sig T
AGE	.172473	.253345	.412837	2.222	.0294
BOLT_LEN	.071830	.104373	.414021	.890	.3762
BOLT_PAT	-.045147	-.070319	.412379	-.598	.5516

* * * * M U L T I P L E   R E G R E S S I O N * * * *

Equation Number 1   Dependent Variable..   CON_RATE

Variable(s) Entered on Step Number
5..   AGE

	.79528
	.63246
Adjusted R Square	.60694
Standard Error	.39496

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	5	19.32762	3.86552
Residual	72	11.23165	.15600

F =   24.77978   Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
SPAN	.036303	.010168	.388359	3.570	.0006
EXCAVAT	4.525553	1.044754	.436440	4.332	.0000
BEAM_TH	-.175709	.049648	-.380332	-3.539	.0007
HEIGHT	-.090650	.040646	-.247998	-2.230	.0288
AGE	.050190	.022586	.172473	2.222	.0294
(Constant)	1.477835	.805473		1.835	.0707

------------- Variables not in the Equation -------------

Variable	Beta In	Partial	Min Toler	T	Sig T
BOLT_LEN	.026850	.038842	.412650	.328	.7442
BOLT_PAT	.034819	.050106	.407413	.423	.6738

End Block Number   1   PIN =   .050 Limits reached.

* * * * M U L T I P L E   R E G R E S S I O N * * * *

Listwise Deletion of Missing Data

Equation Number 1   Dependent Variable..   CON_RATE

Block Number 1. Method: Stepwise   Criteria   PIN .0500   POUT .1000
AGE   BEAM_TH BOLT_LEN BOLT_PAT EXCAVAT HEIGHT   SPAN

Variable(s) Entered on Step Number
1..   SPAN

Multiple R	.69029
R Square	.47650
Adjusted R Square	.46961
Standard Error	.45880

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	1	14.56158	14.56158
Residual	76	15.99769	.21050

F = 69.17748 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
SPAN	.064527	.007758	.690292	8.317	.0000
(Constant)	.068041	.174322		.390	.6974

------------- Variables not in the Equation -------------

Variable	Beta In	Partial	Min Toler	T	Sig T
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BEAM_TH	-.156673	-.208707	.928973	-1.848	.0685
BOLT_LEN	.089994	.123720	.989377	1.080	.2837
BOLT_PAT	-.036055	-.049689	.994266	-.431	.6678
EXCAVAT	.291763	.308560	.585507	2.809	.0063
HEIGHT	-.009603	-.011921	.806737	-.103	.9180

* * * * M U L T I P L E R E G R E S S I O N * * * *

Equation Number 1 Dependent Variable.. CON_RATE

Variable(s) Entered on Step Number
2.. EXCAVAT

Multiple R	.72550
R Square	.52634
Adjusted R Square	.51371
Standard Error	.43931

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	2	16.08471	8.04235
Residual	75	14.47456	.19299

F = 41.67149 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
SPAN	.046968	.009708	.502451	4.838	.0000
EXCAVAT	3.025368	1.076916	.291763	2.809	.0063
(Constant)	-.305482	.213401		-1.431	.1564

------------- Variables not in the Equation -------------

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BEAM_TH	-.267430	-.351855	.483247	-3.234	.0018

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HEIGHT	.059231	.074627	.445037	.644	.5217

* * * * M U L T I P L E R E G R E S S I O N * * * *

Equation Number 1 Dependent Variable.. CON_RATE

Variable(s) Entered on Step Number
3.. BEAM_TH

Multiple R	.76484
R Square	.58498
Adjusted R Square	.56816
Standard Error	.41399

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	DF	Sum of Squares	Mean Square
Regression	3	17.87669	5.95890
Residual	74	12.68258	.17139

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------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
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BOLT_PAT	-.056126	-.085273	.482395	-.731	.4670
HEIGHT	-.231765	-.231656	.414626	-2.035	.0455

* * * * M U L T I P L E R E G R E S S I O N * * * *

Equation Number 1 Dependent Variable.. CON_RATE

Variable(s) Entered on Step Number
4.. HEIGHT

Multiple R	.77927
R Square	.60726
Adjusted R Square	.58574
Standard Error	.40548

Analysis of Variance

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Regression	4	18.55729	4.63932
Residual	73	12.00198	.16441

F = 28.21790 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
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(Constant)	2.022693	.787672		2.568	.0123

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Variable	Beta In	Partial	Min Toler	T	Sig T
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BOLT_LEN	.071830	.104373	.414021	.890	.3762
BOLT_PAT	-.045147	-.070319	.412379	-.598	.5516

* * * * M U L T I P L E R E G R E S S I O N * * * *

Equation Number 1 Dependent Variable.. CON_RATE

Variable(s) Entered on Step Number
5.. AGE

Multiple R	.79528
R Square	.63246
Adjusted R Square	.60694
Standard Error	.39496

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	5	19.32762	3.86552
Residual	72	11.23165	.15600

F = 24.77978 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
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BEAM_TH	-.175709	.049648	-.380332	-3.539	.0007
HEIGHT	-.090650	.040646	-.247998	-2.230	.0288
AGE	.050190	.022586	.172473	2.222	.0294
(Constant)	1.477835	.805473		1.835	.0707

------------- Variables not in the Equation -------------

Variable	Beta In	Partial	Min Toler	T	Sig T
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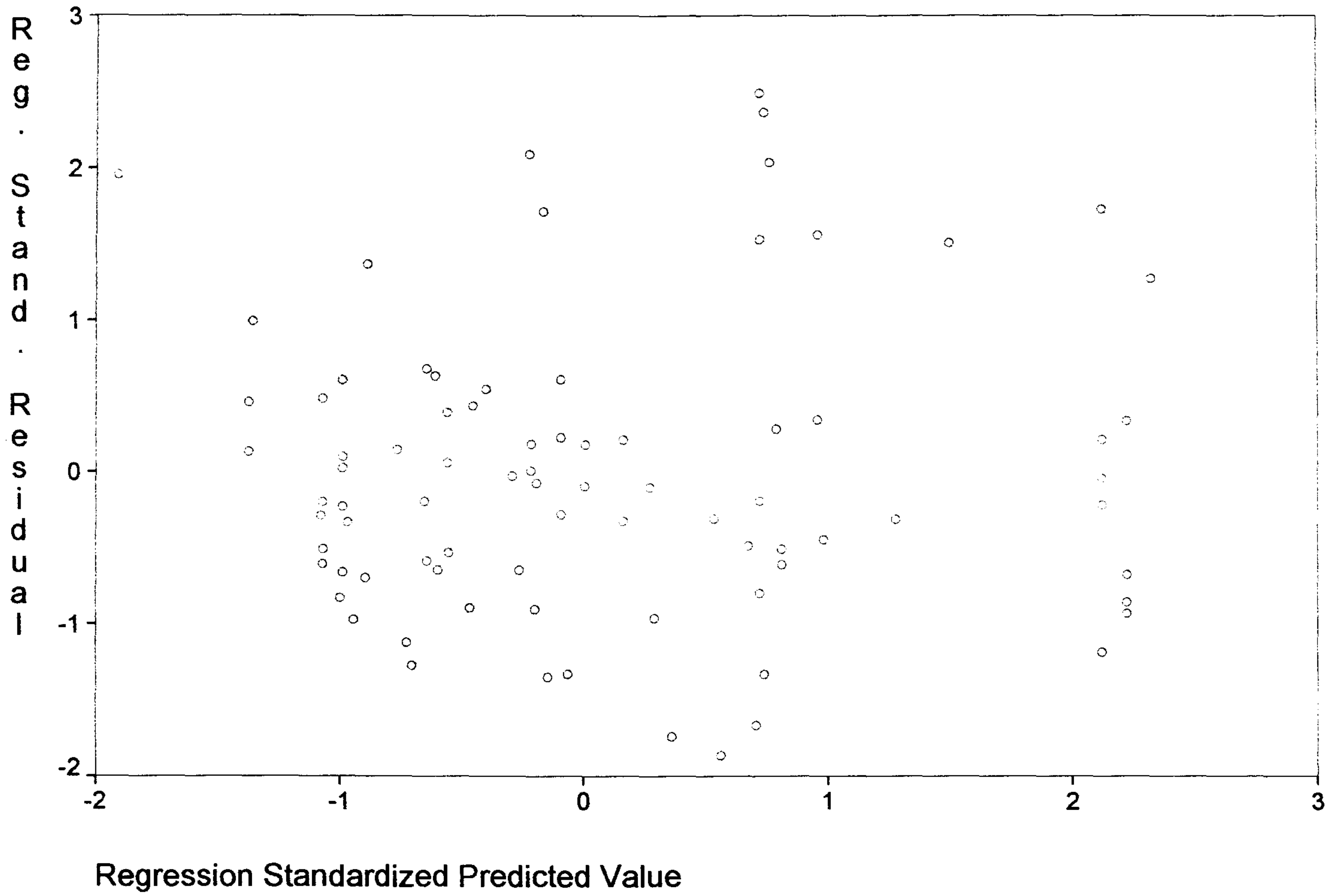
BOLT_PAT	.034819	.050106	.407413	.423	.6738

Scatterplot

Dependent Variable: CON_RATE



ACRONYMS

CH	Contact Handled
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
RH	Remote Handled
SPDV	Site and Preliminary Design Validation
TRU	Transuranic
WIPP	Waste Isolation Pilot Plant