COMPARISON BETWEEN DESIGN CRITERIA AND OBSERVED STRUCTURAL PERFORMANCE OF UNDERGROUND OPENINGS AT WIPP

R.F. Cook and C. Francke

ABSTRACT

This paper discusses the observed structural performance of the underground excavations at the Waste Isolation Pilot Plant (WIPP) in relation to design criteria. The criteria were established at an early stage of the project to define the functional and structural requirements that were to be addressed in the design of the facility. For the underground structural response, the criteria define the requirements for the shaft and shaft liner design, mine design, waste emplacement, retrievability and instrumentation.

The observed structural performance of the underground is determined by the field data that have been collected since excavations were started at the WIPP site. The observations include field measurements of rock and water conditions, as well as maintenance records. The data provide input to design confirmation, performance assessment and form the basis for the design of new underground structures. For this paper, the field data have been compared with the design criteria applicable to ground control to demonstrate that the requirements of the design are met.

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a research and development facility of the U.S. Department of Energy (DOE). Its purpose is to demonstrate the safe emplacement and storage of low and medium level transuranic nuclear wastes in a deep underground salt deposit. Criteria for the design of the facility are provided in WIPP-DOE-71, Revision 4, 1984 (1). They represent the requirements that must be addressed to ensure that the facility adequately fulfills its functional objectives. In general terms, the criteria follow the outline of 30 CFR, Part 57, Mine Safety and Health Administration (2), which is the basic federal code regulating underground metal and nonmetal mining. Additional provisions are included in the criteria to address the particular requirements for a nuclear waste storage facility. For this paper, only those criteria that apply to ground control are discussed. These relate to the maintenance and sizing of openings to ensure that they remain stable, and that creep closure can take place without impacting equipment clearances; confirmation of the geologic continuity of the facility horizon; and, the control of ground water to ensure that none reaches the storage horizon via the shafts.

The criteria that apply in an area of the underground depend upon the particular operational requirements of that area. Five general areas can be identified in the underground that fulfill different functions. These are the shafts, the shaft stations, the access drifts, the waste storage areas, and the experimental areas.

This paper discusses the performance of the first four areas. It does not discuss the performance of the experimental areas where performance will be specific to the particular experiments being carried out.

Geomechanical observations throughout the underground have established actual performance. These in situ observations are particularly important since predictions based on laboratory data and computer models have not as yet provided sufficiently accurate estimates of field performance, due primarily to the inaccuracy of laws governing the time dependent response and the failure of salt. Direct observation and extrapolation of field data therefore, provides the most effective method for design confirmation and for predicting future performance. In particular, the creep closure of openings specifies their dimensions relative to initial sizes and establishes the time period during which operating clearances for equipment can be maintained. Also, fracture mapping and records of support installations qualitatively define conditions and document the deterioration of the openings with time. The water pressures and observation of leakage in the shafts establish the effectiveness of the shaft liners and seal systems in the upper strata.

In situ geomechanical data have been taken since excavations were first made in 1979. They include data from a Site and Preliminary Design Validation Program. This program was carried out to confirm structural performance and is reported in the Design Validation Final Report, 1986 (3). Although the program is now complete, routine monitoring of excavations continues. Field data and surveys documenting underground conditions are now reported on an annual basis in the Geotechnical Field Data and Analysis Reports (refs. 4, 5 and 6).

BACKGROUND

The underground facility at WIPP can be divided into two parts. An experimental area is located in the north part of the facility and areas for storage of CH and RH TRU wastes are to the south. The experimental area contains tests that address technology development and performance assessment needs; and, rooms established at an early stage of underground development for the site and preliminary design validation program. The storage area is under development with Panel 1 presently the only storage area excavated. It is intended to use this panel during a 5 year period to demonstrate safe emplacement and storage of waste and to address field performance assessment needs.

During the demonstration period, the waste must be stored such that it can be easily retrieved. However, once safe disposal has been demonstrated, the facility will be turned into a repository for permanent waste emplacement. The design criteria define both the requirements for permanent emplacement and those for temporary storage.

The low level (Contact Handled) transuranic (TRU) waste will be contained in 55 gallon drums. The drums will be stacked three high and a room completely filled will contain about 6000 drums. The medium level waste (Remote Handled) transuranic (TRU) wastes, contained in canisters will be emplaced in horizontal boreholes in the ribs of excavations. For the demonstration period, the RH TRU waste will be stored in a separate area from the CH TRU waste. Once the safe disposal of waste has been demonstrated, the RH TRU canisters will be emplaced throughout the storage area in unlined holes as dictated by the receival rate of the waste.

Underground Structures

The underground structures discussed in this paper are the shafts, the shaft stations, the access drifts and the waste storage areas. The shafts pass through the entire stratigraphic sequence overlying the facility horizon. Three shafts are presently completed at the site. These are the Construction and Salt Handl :;, Waste Handling and Exhaust Air. A fourth shaft is under construction. This will provide an air intake for ventilati. ı purposes. Some of the rocks intersected by the shafts require support and some are potential sources of water ingress to the facility horizon. Criteria relating to the control of water in the shaft and the support of the excavations ensure that the sh 'ts remain functional throughout the life of the facility.

Two of the shafts have shaft stations for servicing the underground facility. These stations represent two of the largest and oldest of the WIPP underground openings. Both openings must be maintained throughout the life of the facility. They must be stable and of sufficient size to permit creep to take place without impacting transportation equipment.

The access drifts provide access and support the ventilation system throughout the facility. As with the shaft stations, the access drifts must remain stable and be of sufficient size to permit creep to take place without impacting transportation equipment over the operating life of the facility.

The waste areas must meet criteria that relate to emplacement and retrievability. They must be of sufficient dimensions to permit equipment requirements depending upon whether retrievability remains an option in a particular panel.

Geology

The facility horizon is located about 655 m below surface level in thick Permian Salt Beds. A general section showing the stratigraphy of the site is given in Fig 1. The strata sequence consists of flat-lying interbedded sandstones, mudstones, anhydrites, dolomites and halites. Near horizon geology is shown in Fig 2. It shows anhydrite and clay layers underlying and overlying the designated facility horizon. The selected horizon is continuous salt about 7.5 m thick.

SHAFT AND SHAFT LINER DESIGN CRITERIA

Structural Stability

The design criteria state that the shafts shall remain structurally stable throughout the operating life of the facility and for the period required for its decommissioning. The upper sections of the shafts are lined and this reduces deterioration of the rocks and prevents water ingress. The shaft liners are designed to take hydrostatic pressures developing in the strata overlying the evaporite strata. The shaft liners are supported by shaft keys which act as a foundation for the liner. The keys are located in the salt and are subject to lateral loading from the inward creep of the salt strata. Although pressures were not expected to develop immediately following emplacement of the keys due to shrinkage of the concrete, the lack of significant build up of load after 5 years indicates low creep rates in the area about the keys. Through the salt, the shafts are unlined and rockbolts and mesh are installed to prevent spalling. In addition, shaft inspections are carried out on a regular basis to confirm that the shafts remain in good condition.

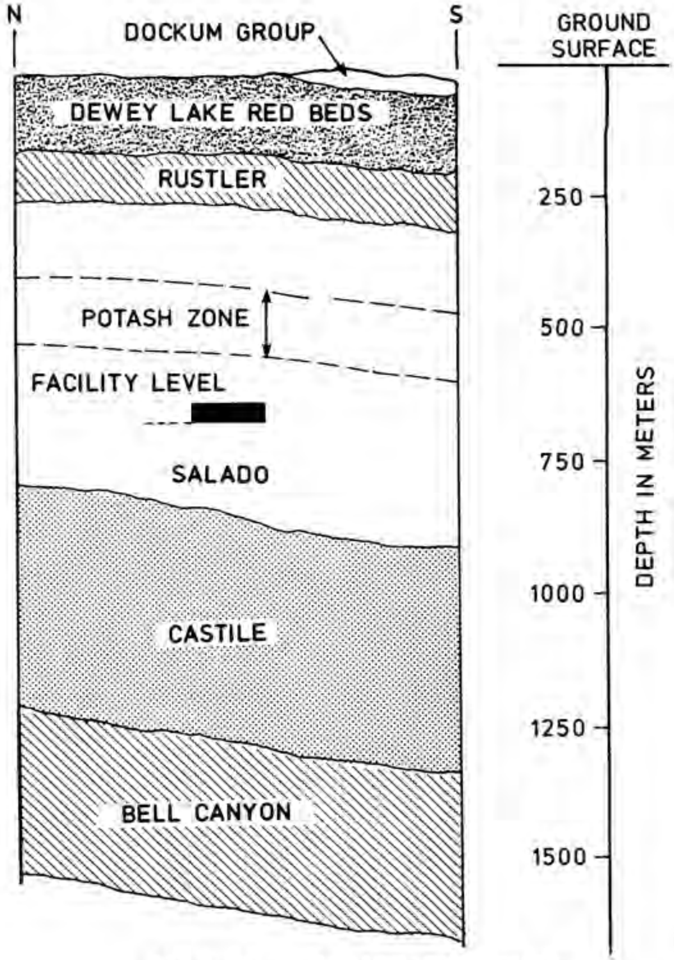

Fig. 1. Generalized Site Stratigraphy.

Maintenance of Minimum Dimensions

The design criteria state that shaft wall deformations shall not interfere with the functions of the shafts or affect the safety of the shaft operations. For each shaft, minimum cross sectional dimensions have been defined and each shaft is constructed to ensure that this is not violated over its operating life. In the upper sections of each shaft, the excavation is lined and the liner prevents shaft closure and maintains the specified opening size. In the lower sections through the salt strata, the shafts are unlined. For each shaft, sufficient radial clearance must be left to ensure that creep

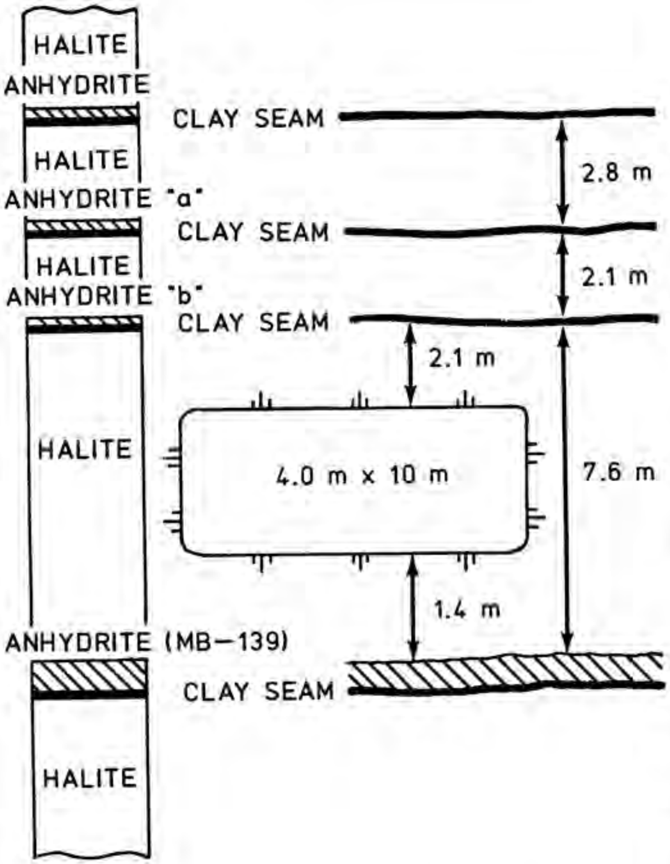

Fig. 2. Generalized Near Horizon Geology.

closure over the life of the excavations does not interfere with the operational requirements and clearances in the shafts.

In Table I, the 25 year closure prediction is based on the total observed closure to date and the extrapolation of the 1988 closure rates as steady state rates over the remainder of the 25 year period. These provide conservative estimates of shaft closure since rates can be expected to reduce with time. The results from Table I confirm that the design requirements are being met in the C and SH and the Waste Shafts but that further reductions in closure rate are needed for the Exhaust Shaft to meet the design requirements. It is anticipated that closure rates will reduce over the next several years and that the 25 year closure will not exceed design limits.

TABLE I

Predictions of 25 Year Closure in the Unlined Sections of the Shafts

shaft	unlined shaft diameter (m)	design basis (2)	predicted (4)	observed (4)
		diametral closure (mm)	diametral closure (mm)	radial closure rate (mm/year)
C and SH	3.66	150	123	2.75
Waste	6.10	188	180	3.65
Exhaust	4.58	150	200	4.28

Control of Ground water Flow

The design criteria indicate that uncontrolled groundwater shall not reach the storage horizon via the shafts. At WIPP, three principal water-bearing zones overlie the facility. They are the Magenta and Culebra Dolomite members of the Rustler Formation and the Rustler/Salado contact (see Fig. 1). To minimize water inflow into the shafts, they are lined through the strata and seals are installed behind the liners.

Fig 3 compares the measured water pressures in the shafts at various depths with the design liner pressures. The plot shows that the water pressures remain below the design levels. The effectiveness of the seals is shown in Table II. This indicates that although remedial measures in the form of grouting have been required, the performance of the seals is now satisfactory and ingress of water to the facility horizon has been reduced to a minimum.

Table II

Flow Observed in Shafts during Construction

Shaft	Flow during Construction (liters/min)	Present Conditions
C and SH	6.8	minor leaks from "tell tale" drains
Waste	1.1-2.3	minor leaks from construction joints
Exhaust	1.5-1.9	dry
Air Intake	1.9	under construction

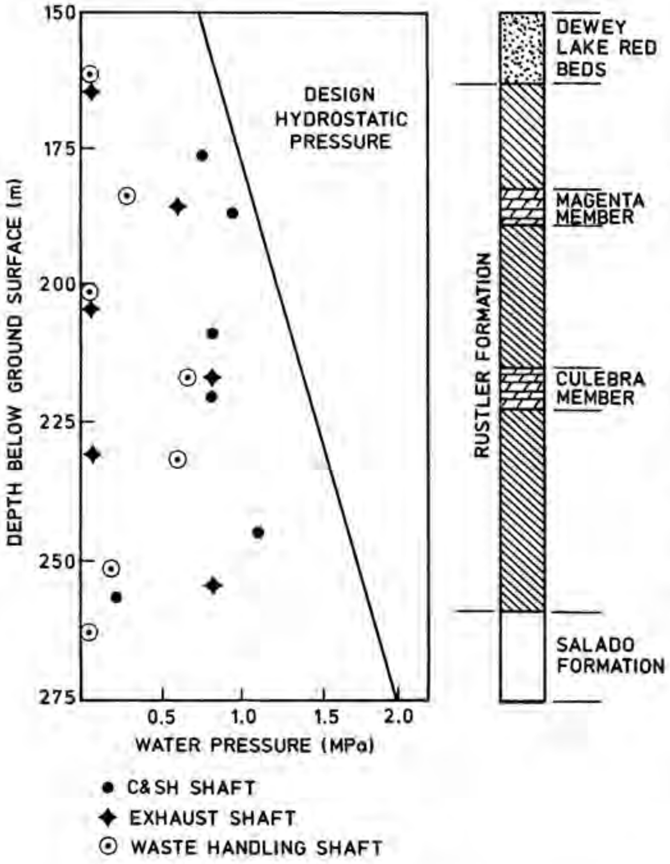

Fig. 3. Water Pressure Build-up Behind Linings in Shafts.

MINE DESIGN CRITERIA

Structural Stability

Two criteria define the requirements for structural stability of the openings. These state that the openings shall serve the underground facility for the 25 year life of its operation, and they shall be designed to minimize the potential for rock fracturing.

Shaft Stations: Being the first excavation underground, the C and SH shaft station was excavated using drill and blast techniques in order to provide room to assemble the mining machine and to establish ventilation. Roof deterioration in the form of fracture development and high creep rates has been observed in this station. This has occurred in the immediate roof that comprises a beam approximately 2 m thick below the anhydrite "b" layer. Rockbolting, by means of point anchored and full column resin bolts was used as roof support. However, deterioration continued and further remedial actions were needed to maintain long term performance. These included the removal of the rock to the anhydrite "b" layer, and the installation of rock bolt roof support.

Modifications were also carried out in the Waste Shaft Station in response to closure rates and floor heave that were higher than estimated when the station was designed early in the project. These included trimming of both roof and floor. Observations have indicated none of the fracturing and separation found in the roof of the C and SH Shaft Station occurring in the Waste Shaft Station.

Access Drifts: As the underground openings have aged, more maintenance has been required. Maintenance has included scaling of loose surface rock and bolting of "drummy" or fractured areas. Prior to August 1986, approximately 3000 bolts were installed. During the period from August 1986 to July 1987, approximately 4000 bolts were installed and during the period July 1987 to July 1988, over 5000 rock bolts were installed. The bolting records indicate not only additional lengths of drift mined each year but also the deterioration of older excavations.

Excavation effects surveys carried out on an annual basis demonstrate that rock conditions deteriorate with age and the relationships are summarized in Fig 4. Based on

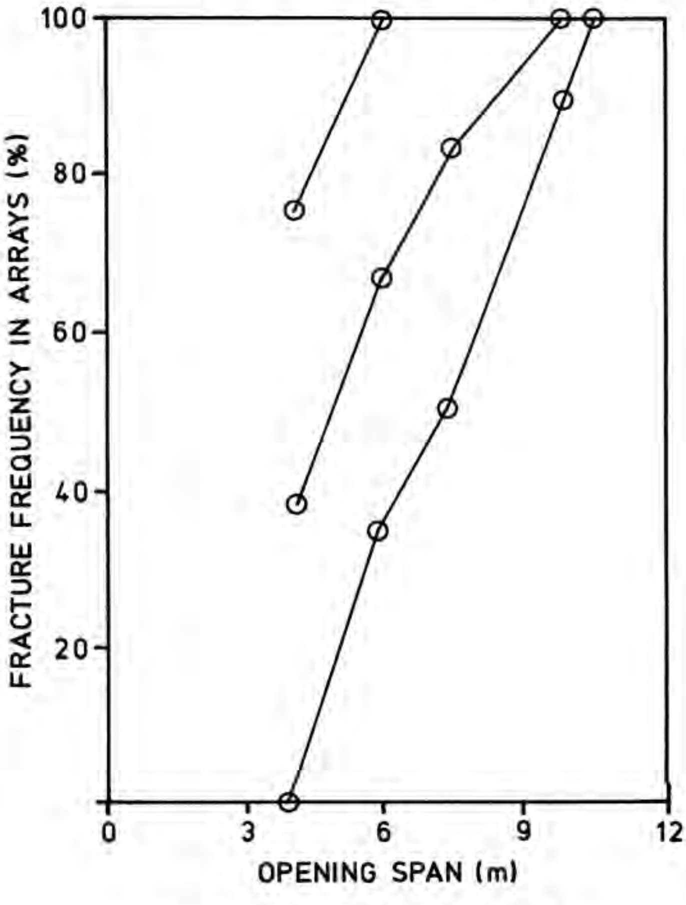

Fig. 4. Excavation Effects Program.

these surveys, maintenance requirements of the underground openings are expected to increase as the openings age. The accepted site maintenance practices have proved adequate in controlling conditions in the access drifts.

Surface Subsidence

The design criteria state that surface subsidence resulting from underground excavations shall not exceed 25 mm within a 150 m radius of the Waste Shaft. The design has maintained an excavation ratio within the shaft pillar of less than 15% in order to minimize surface subsidence.

Geologic Continuity

The design criteria state that the excavation and pillars shall be located and dimensioned to avoid geologic discontinuities (such as fractures, clay seams and geologic folds). When the shafts first reached the facility horizon, an additional anhydrite layer was encountered not previously identified by the site exploration program. This reduced the uninterrupted thickness of halite above the facility roof level to 2 to 2.5m in the waste storage areas. This was not sufficient to alter the planned level of the facility. Since the facility horizon was opened up, an extensive drilling program and the underground development has proved the geologic structure at the WIPP site to be uniform and confirmed that no major geologic discontinuities are encountered at the facility location.

In situ Verification of Salt Performance

The design criteria states that the predicted behavior of the salt shall be verified by in situ testing before proceeding with the construction of the storage area. For this purpose, a Site and Preliminary Design Validation Program was carried out. This included the excavation and monitoring of a panel of four test rooms with dimensions similar to those proposed for the waste storage rooms. In addition, geomechanical data has been collected throughout the facility to establish the in situ performance of the salt strata. The data has been used to determine mechanisms that explain observed performance. One such proposed mechanism for the behavior observed in the storage room openings is given in Fig 5.

Maintenance of Minimum Opening Dimensions

The criteria states that excavations shall be designed to accommodate creep closure and maintain the minimum dimensions required for the operating life of an opening. Since the openings have a variety of operational functions, each opening has a set of minimum dimensions that must be maintained over its required time spans. The shaft stations and the access drifts must be accessible throughout the life of the facility. The waste storage areas, on the other hand, require access over limited periods of time depending on whether they are being used for permanent or temporary storage. This is discussed further under Emplacement Criteria.

An empirical evaluation based on field data has established estimates of room closure rates that reflect initial opening dimensions and the time since excavation. Predictions of room closure based on these equations are given in

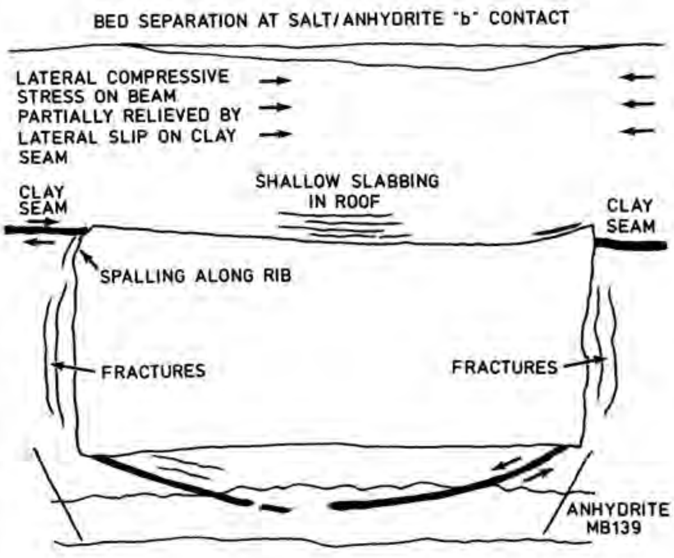

Fig. 5. Observed Performance of 4 m x 10 m Rooms.

Fig 6. These results indicate a wide range in values associated with a closure rate prediction. However, the predictions do establish bounds on the extent of creep closure that can expected for a particular room cross section after a specified time period following opening excavation.

Backfill Requirement

For permanent disposal of waste, storage rooms will be backfilled to reduce void volume and bring about early consolidation of rooms. The specification for the backfill depends upon technology development. It is expected to be mainly crushed salt but may contain additional materials to absorb brine and gases generated by the waste. For the demonstration period, it is not intended to backfill storage rooms in order to allow easier retrieval conditions.

Isolation of Panels

The criteria states that the mine layout shall permit the isolation of panels of rooms by means of plugging once the rooms in a panel are filled. Entries to the panels are minimized in size in order to minimize rock fracturing and a seals program is being undertaken as part of the technology development program to design an appropriate seal system.

EMPLACEMENT CRITERIA

The criteria states that underground storage rooms and access drifts shall be designed to be compatible with the waste transport vehicle and with waste container sizes, shapes, weights, stacking configurations and handling requirements. To meet these criteria, the design has specified 4m high by 10m wide openings with a mining tolerance of -0, +300 mm. The openings are separated by 30 m wide pillars. The minimum opening dimensions include an al-

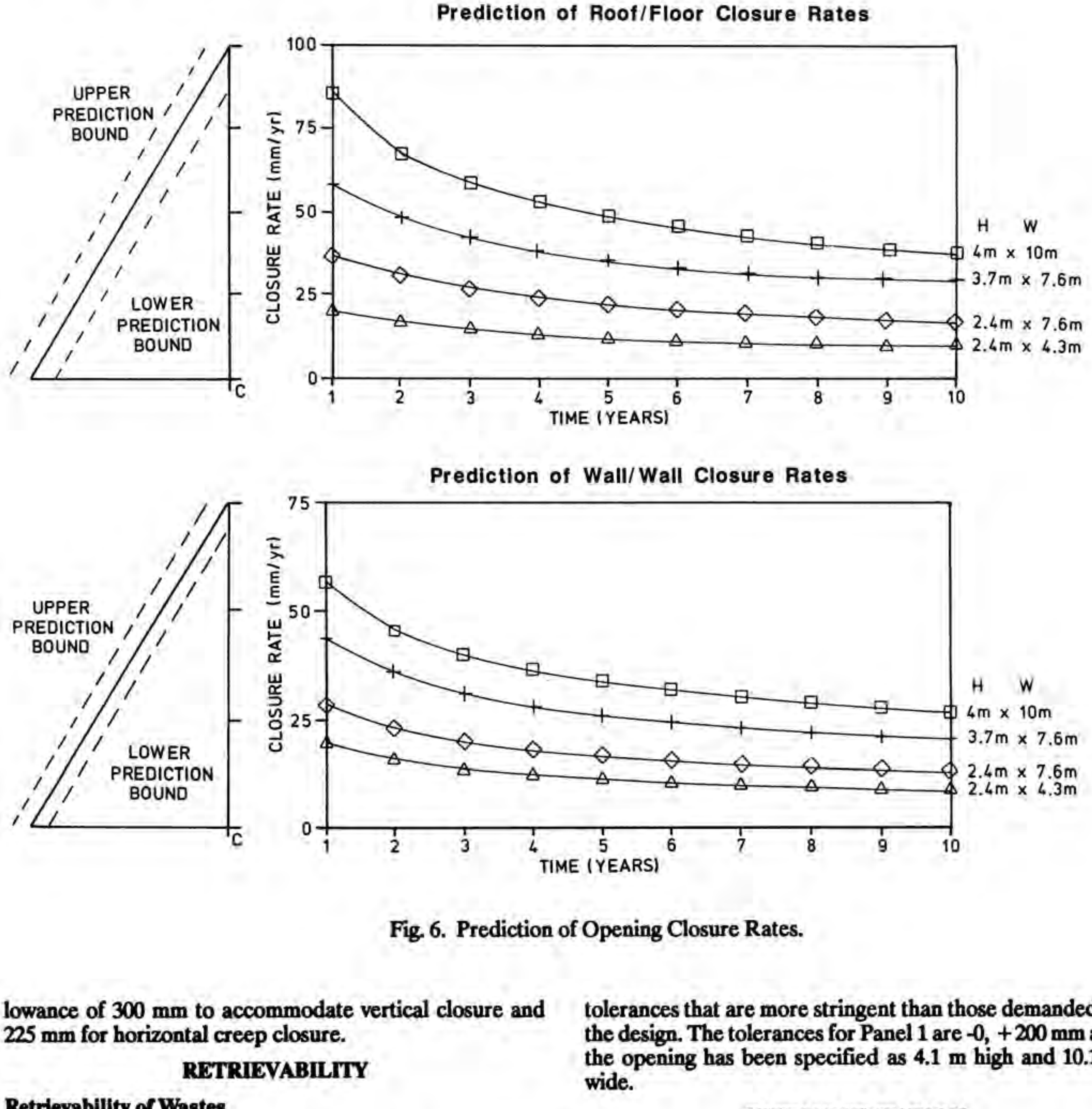

Fig. 6. Prediction of Opening Closure Rates.

lowance of 300 mm to accommodate vertical closure and 225 mm for horizontal creep closure.

RETRIEVABILITY

Retrievability of Wastes

The criteria states that all wastes emplaced at WIPP shall be retrievable until such time as the pilot plant is converted to an operational repository for the permanent disposal of wastes. For the demonstration period, additional measures have been carried out in Panel 1 to maintain the retrievability option. These have included roof bolting to support the immediate roof beam and measures to maintain equipment clearances. These measures have included the driving of pilot drifts and excavating the pilot drifts to almost full size prior to trimming excavations to final dimensions. This phased approach distresses the rock by the pilot drift development and removes the initial transient creep. Additionally, the mining in Panel 1 has been carried out to tolerances that are more stringent than those demanded by the design. The tolerances for Panel 1 are -0, +200 mm and the opening has been specified as 4.1 m high and 10.1 m wide.

INSTRUMENTATION

The criteria states that underground instrumentation is required to measure phenomena important to the performance of the facility. Instrumentation has been installed throughout the facility to define structural performance. The results of these programs have been recorded in the Design Validation Final Report, 1986 (2) to confirm the preliminary design and in the periodic Geotechnical Field Data and Analysis Reports (4,5 and 6) to document routine facility monitoring of performance.

CONCLUSIONS

The criteria for the performance of the underground establish the requirements for shaft and shaft liner design, mine design, waste emplacement, retrievability and instrumentation. The three main requirements for structural performance of the underground are the maintenance of operating clearances; the maintenance of roof conditions that deteriorate with time and require the installation of local rock bolt support; and, the control of water inflow to the facility horizon.

The observed geomechanical data provides monitoring of structural performance to confirm that the design requirements are met. The routine closure measurements taken throughout the underground facility monitor opening sizes to ensure that operating clearances are maintained. The surveys of rock conditions establish the deterioration of openings with time and ensure that adequate measures are taken to identify and support locally poor conditions. Finally, the observations in the shafts establish the effectiveness of the shaft liner and sealing systems in controlling groundwater inflow. These monitoring programs are integral to the continued confirmation of design performance and to the assessment of operating requirements.

ACKNOWLEDGMENTS

The paper is based on data collected on behalf of the U.S. D.O.E. by organizations working on the WIPP Project, including Westinghouse, the Managing and Operating Contractor and Bechtel, the Architect/Engineer. The views expressed in this paper are those of the authors and do not necessarily reflect those of the US DOE.

REFERENCES

1. U.S. D.O.E., 1984, Design Criteria, Revised Mission Concept - IIA, Revision 4, Albuquerque, New Mexico, WIPP-DOE-71.
2. Federal Metal and Nonmetallic Mine Safety and Health Regulations, 30 CFR 56 and 57.
3. U.S. D.O.E., 1986, Design Validation Validation Report, prepared by Bechtel National Inc., San Francisco, California. DOE-WIPP-86-010
4. U.S. D.O.E., 1986, Interim Geotechnical Field Data Report, prepared by Bechtel National Inc., San Francisco, California. DOE-WIPP-86-012
5. U.S. D.O.E., 1987, Geotechnical Field Data and Analysis Report, prepared by Westinghouse Electric Corporation, Carlsbad, New Mexico. DOE-WIPP-87-017
6. U.S. D.O.E., 1988, Geotechnical Field Data and Analysis Report, in preparation
7. Borns D.J. and Stormont J.C., 1988, An Interim Report on Excavation Effect Studies at the Waste Isolation Pilot Plant: The Delineation of the Disturbed Rock Zone, Sandia National Laboratories, Albuquerque, New Mexico, SAND87-1375.