EFFECTS OF WIRE ROPE IN MITIGATING A WASTE SHAFT ACCIDENT

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ABSTRACT

This report describes the empirical test program conducted on a 1/22-scale model of the WIPP facility. The model was designed to study the actions and effects of the wire rope used in the Koepe or friction-type hoist during various accident scenarios. It is assumed that the hoist cable breaks and the cab (or shaft conveyance) falls to the bottom of the shaft during such an accident. The report gives the results of the study and makes recommendations for a continuing program of testing and redesign of the shaft to mitigate the effects of such an accident. The wire rope is shown to act as a good shock-absorbing material.

BACKGROUND

Studies of facility operations for the Waste Isolation Pilot Plant (WIPP) have identified a need to consider in the design a potential accident involving a free-falling hoist cage. Such a scenario customarily envisions an impact that results in the rupture of a high-level waste transfer cask and/or a waste canister, with release of large amounts of radioactive material. Worst-case analyses of such an accident have assumed that the hoist cage would impact the bottom of the shaft at free-fall velocity with no shock-absorbant material at the base of the shaft. Such an assumption is unrealistic. The hoist system envisioned in the preliminary design is a Koepe or friction-type hoist (Fig. 1), with six 1-3/8-in. flattened-strand hoist ropes and four 1-3/4-in. tail or balance ropes. If the hoist dropped from any appreciable height, a large volume of the tail rope would pile up in the bottom of the shaft and act as a shock-mitigating material. The purpose of this investigation is to study the effects of the wire rope in such an accident.

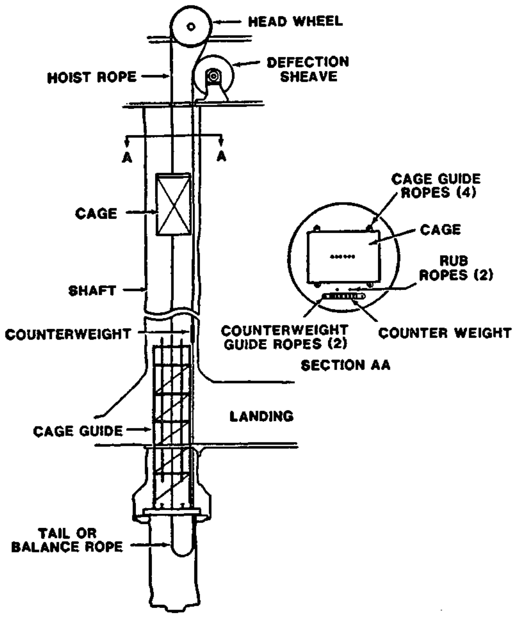

Fig. 1. Elements of a Koepe or Friction Hoist

The draft test plan was approved before the start of testing, and the necessary mechanical components were designed, fabricated, and installed by the end of September 1979.

This report covers testing performed at Sandia from October 1979 through February 1980. The results have indicated where additional testing and design are desired.

DESIGN BASIS FOR EXPERIMENT

The full-scale waste shaft used in the preliminary design is about 22 ft in diameter at the regions of interest for this study. The depth is about 2200+ ft from the headframe to the waste-disposal horizon.

The test facility used is located in Area III of Sandia National Laboratories, Albuquerque, New Mexico. The basic element consists of a 1-ft-dia. tube that is 100 ft long. This sets the scale factor for the experiment as 1:22.

Southwest Research Institute (SwRI) provided consulting services during the early experiment planning. Later they provided data reduction, limited analyses and interpretation of results, and their conclusions and recommendations for further study. An early result of this effort is the report "Scale Modeling of Hoist Accident in the WIPP Facility" by W. E. Baker and P. S. Westine. This report was written before the design change of the WIPP Facility from a two-level repository to a one-level repository. This accounts for the scale factor of 1:19 cited in the SwRI report as compared to the 1:22 scale factor actually used in the design of the experimental setup. This report develops the equations used in the design of the scale model and in the interpretation of the experimental results.

Stainless steel aircraft cable was used in the model to simulate the hoist and tail ropes. The sizes of this cable (readily available commercially) and their approximate equivalent full-sized cable are shown at the top of the next page.

Model Cable Size			Equivalent Full-Sized Cable	
1/16-in.	7x19	0.007826 lb/ft	1 3/8-in.	3.79 lb/ft
5/64-in.	7x19	0.01166 lb/ft	1 3/4-in.	5.64 lb/ft
3/32-in.	7x19	0.01757 lb/ft	2 1/16-in.	8.50 lb/ft
1/8-in.	7x19	0.03060 lb/ft	2 3/4-in.	14.81 lb/ft
1/16-in.	7x7	0.007540 lb/ft	1 3/8-in.	3.65 lb/ft
3/32-in.	7x7	0.01541 lb/ft	2 1/16-in.	7.46 lb/ft
1/8-in.	7x7	0.02893 lb/ft	2 3/4-in.	14.00 lb/ft

The 7x7 construction (7 strands of 7 wires each) is the best analog for the hoist rope; the 7x19 construction (7 strands of 19 wires each) is the best analog for the tail or balance rope.

The 5/64 in. 7x19 cable, although a catalog item, is made on special order only. After early tests indicated that the experiment would be improved with the use of this size, the cable was placed in order and received in January 1980. All other types were available from the beginning of the test series.

In addition to the hoist and tail ropes, there are other stationary cables in the shaft. These are:

Four conveyance guide ropes
Two counterweight guide ropes
Two rubbing ropes

In the accident scenario, it is assumed that these ropes would remain in place. They would guide the falling conveyance and counterweight down the shaft, and prevent the conveyance and counterweight from interfering with each other. We chose 3/32-in. solid stainless-steel wire as a reasonable simulation for these stationary ropes. Test results indicate that these assumptions were valid.

PROGRAM DESCRIPTION

Even before installation of the shaft furnishing (the cage guide and associated structure), guide cables, and rub ropes, we ran rough scoping tests by using the bare tube and hand-held release on both the smallest and most flexible (1/16 in. 7x19) and the largest and stiffest (1/8 in. 7x7) cables in our stock. In each case, four 100-ft lengths of the cable with the top ends taped together were dropped.

These preliminary rough scoping tests are described in a Memo of Record dated August 6, 1979. Some of the results of those tests are as follows.

- The cable dropped freely, i.e., it was not appreciably slowed by rubbing on the side of the 100-ft tube.
- The cable was easily contained in the 4-ft-long experimental section when it was dropped without the shaft furnishing model and the guide and rub ropes in place.
- Camera coverage showed that the cable appeared to concentrate in the outer portion of the tube, apparently because of centrifugal forces caused by cable buckling.
- The tests showed that we can expect the cable to present a large volume of a tangled mass of cabling at the bottom of the shaft; the volume of the tangled pile is 25 to 50 *times* greater than the volume required to contain the cable at its maximum theoretical density (i.e., not considering crushing of the wire rope configuration).

As soon as the component parts for the scale model test setup were received, the complete test setup (the shaft furnishing, guide cables, rub ropes, cage and counterweight) was assembled. This test setup was completed by September 28, 1979, and was reviewed by Drs. Wilfred E. Baker and James L. Rand, consultants on model testing from Southwest Research Institute.

Testing according to the procedures detailed in the previously approved test plan commenced the first week of October, 1979, with the cable sizes then on hand. These tests consisted of slow lowerings and drops of both cage and counterweight. Summary descriptions of the tests are given on the following pages.

A data sheet was filled out for each test configuration. The configuration consisted of a set of hoist ropes or tail ropes (or both), and either the cage or the counterweight (or both). These data sheets were quick field notes and are not complete; they are supplemented by comment forms that elaborate on development of the testing and also contain additional observations.

Milliken camera coverage (400 frames/s) was attempted 19 times, with usable data collected 13 times. The Scopic 16-mm movie camera (running at either 24 or 64 frames/sec) has been used as a general record of the tests and has proven very valuable in the reviewing tests. It was used on 22 tests, with 100% data recovery. Still pictures have been taken of the postshot results. All still photos taken are available, as are all the motion-picture films.

Load-deflection tests and X-ray pictures were taken on sample piles of dropped cable. Densitometer scans are available and support the qualitative impression of the degree of uniformity of the cable mass. These load-deflection curves from the X-Y plotters are also available.

DATA ANALYSIS

The series of tests resulted in a mass of data that lends itself to several different methods of analysis. One of the most obvious results was that provided by simple observation of the behavior of the wire rope. This type of result is substantiated by the still- and motion-picture coverage of the tests. The film was to be analyzed on a "Vanguard" film reader, which provides displacement (position) of the cage as a function of time.

A third type of data resulting from the drop test consisted of load-deflection curves on representative configurations of cable. The shaft-furnishing and base assembly was designed so that it could be removed from the bottom of the tube and taken to a universal testing machine. The cage was removed and replaced by a ram with the same dimensions as the base of the cage. Then load-deflection tests were run on the nested cable.

X-Ray tests were also carried out during these load-deflection tests. Before removing the cage, the assemblies were taken to the X-ray laboratory where pictures were taken of the cable configuration in three mutually perpendicular directions.

Finally, we attempted a limited number of accelerometer measurements of the deceleration of the cage during the drop tests.

Each of the above types of testing is discussed in the following sections.

STILL- AND MOTION-PICTURE CAMERA COVERAGE

As noted in the data sheets, both still and motion pictures were obtained on most of the drops. In addition, there are pictures of the test setup and the design drawings of the component parts of the test setup. Copies of the motion-picture films made during the drops are available from Sandia National Laboratories. Still photographs are also available.

SwRI RESULTS

As discussed earlier, personnel from SwRI were under contract during these tests to provide consultation on the design of the experiment and some data analysis, particularly on the 400-frame/s coverage by the Milliken camera and analysis of the load-deflection curves. SwRI had a Vanguard film reader available for use on this program. The various status reports, data reports, short studies, and their conclusions and recommendations constitute a large portion of the work on this program.

The analysis by SwRI of the Milliken camera data and the analysis of the load-deflection data are the bases for many of the conclusions reached in this experiment.

RESULTS OF X-RAY ANALYSIS

In discussions early in the test program with Sandia's nondestructive testing organization, it was decided to X-ray the "nest" of cabling caught in the shaft furnishing and to experiment with various ways of analyzing the results. The results indicate that the nest of cables is a mass that is fairly uniformly distributed, with the smaller diameter cable predictably slightly more compact at the end of the drop. Because no arresting device was used to catch the cage, the resulting nest was compressed to a greater density in the vertical direction; it has sprung back to the final position and density. Generally, only minimal damage was noted in the cables after such a drop, and that occurred only when a cable was caught between the cage and the furnishing, or when a cable was snagged by the guides that project above the top of the furnishing.

ACCELEROMETER DATA

On the last five drops, moderately successful attempts were made to gather accelerometer data. These data are reasonably consistent with the values inferred from the optical methods. C. M. Stone of Sandia was requested by the author to assist in the evaluation of these data. He made recommendations for modeling the problem for a computer simulation and suggested ways of continuing such an effort.

CONCLUSIONS AND RECOMMENDATIONS

This study is only the first phase of a multiphased program to investigate the effects of the wire rope in mitigating a waste shaft accident. Because of fiscal restraints, even this first phase was not continued to its logical conclusion. With the existing test setup, more tests could have been run that would have materially improved the data base. Moreover, with relatively low cost, tests could have been run that use the equivalent energy approach. Continued development of methods to improve accelerometer data is strongly recommended.

Conclusions

The major conclusions of the study are as follows.

1. Dropping the cage with the full complement of ropes from the full height has always caused the cage to be "caught" (or stopped) well above the bottom of the shaft, although the "catch" was marginal when the 1/16-in. hoist and tail ropes were used.
    - When dropped under the cage from full height, the two 1/8-in. 7x19 tail ropes used by themselves (without hoist ropes) did form a nest. The tail ropes under the counterweight when the counterweight is dropped from full height have not piled up in such a manner as to divert the counterweight into the cage. The fact that the wire rope tends to "nest" on top of the shaft furnishing can provide an excellent built-in mechanism to mitigate shock. The shaft furnishings could be designed both to increase the tendency of the cable to nest and catch the cage, and to act as a crushable shock mitigator.
    - The cable is a good shock-mitigating material. No appreciable damage has been evident on the models. The X-ray pictures of the cable after a drop indicate that it is a fairly uniformly distributed mass when piled up at the bottom of the shaft (inside the furnishing). The load-deflection characteristics of the cable pile at the bottom of the shaft are those of a very nonlinear spring with a stiffening nature. The way that the cable behaves seems to be generally predictable and repeatable.
2. It would seem prudent to design some minimum shock mitigation into the bottom of the cage and into the crash beams for those drops where only a small amount of cable is deposited before impact.
3. The volume of the wire rope underneath the cage (as tail rope) is a linear function of the height from which the cage is dropped. If friction is ignored the energy in the cage at impact is likewise a linear function of height. These factors act in opposite directions in their effect on the peak accelerations produced in a drop. The need to answer the question of how the accelerations vary with drop height is a major reason for conducting the experimental testing program. Higher drop heights give longer acceleration pulses,

but it may well turn out that the peak accelerations are higher for the lower-height drops. Our work to date indicates that the peak g-levels at the half-height drops are as high or perhaps higher than those for the full-height drops.

Recommendations

The recommendations for future study include the following:

1. Using a design with fewer larger diameter ropes of stiffer construction. These stiffer ropes tend to nest on the top of the furnishing more readily than does a larger number of the smaller, more flexible ropes.

2. Reanalyzing the existing Vanguard data set by using data-smoothing techniques. This would permit a better check with the peak acceleration predicted from the various methods of analysis suggested by both Rand and Stone.

3. A more complete computer modeling of the drop. This would include a model of the wire rope as a uniformly distributed mass (as shown by the X-ray pictures) and a load-deflection curve of the wire rope.

4. Using the 1:22 scale-model test setup (Phase II testing) to run tests with a redesigned shaft furnishing and base, and using a cage mass of 220 lb to investigate the effects of an equivalent energy drop. These tests should be instrumented with an upgraded accelerometer system. The data should scale according to the prediction made by Dr. James Rand of SwRI. These tests should also have high-speed camera coverage.

5. Depending on the results of the Phase II testing, Phase III testing could be run on a 1/4-scale test setup on the Nevada Test Site. The cost of such an effort is estimated in a memo from Fenix & Scisson, Inc. (dated August 15, 1979, Ortega to Ellett) as $116,230 for one drop. The cost of more than one test in a series would produce some cost reduction per test, but the uncertainties associated with the cost estimate make it difficult to estimate its amount. A rough figure of $100,000 per test is a reasonable starting point for estimating the cost of a series of tests containing three or more planned drops.

We have demonstrated in this limited test program that the wire rope acts as an effective shock mitigator to reduce the effects of the postulated worst-case accident involving a free-falling cage. The test program has also led to suggestions for redesigning the shaft furnishings, use of other cables, etc, that would even further reduce adverse effects.