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ENGINEERING AND SCIENTIFIC RESEARCH AT WES, OCTOBER 1972.(U)
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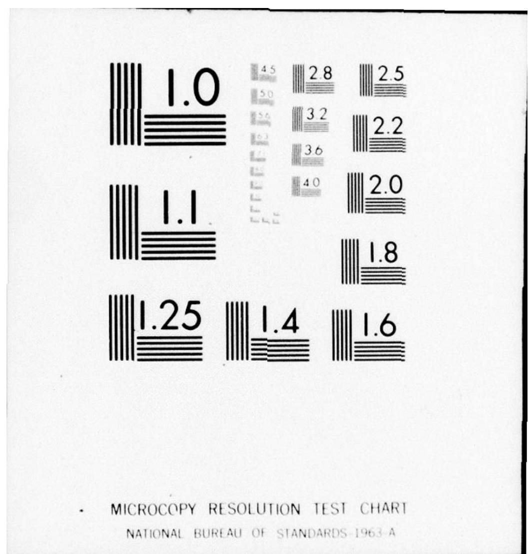
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# ENGINEERING AND SCIENTIFIC RESEARCH AT WES

Miscellaneous Paper 0-72-2 October 1972



**WATER WAVES GENERATED BY LANDSLIDES IN RESERVOIRS,** *by D. D. Davidson, Hydraulics Laboratory*

The destructive capacity of landslide-generated water waves has been well documented for many occurrences around the world. However, the ability to predict wave characteristics which would result from a potential landslide is still in the development stage. Predictions of the heights of landslide-generated waves to date have been confined to (1) correlation with historic occurrences, (2) correlation of landslide energy with underwater explosion energy and with explosion-generated wave heights, (3) two-dimensional hydraulic model studies, and (4) a few small-scale three-dimensional hydraulic model studies.

Current interest of the Corps of Engineers in landslide-generated waves is a result of concern for potential landslide areas in the Libby Dam project reservoir. This Corps project, located on the Kootenai River in northwestern Montana, is under construction with final reservoir filling scheduled for the spring of 1973. An evaluation of the possible effects of landslide-generated waves in the Libby Reservoir was undertaken to determine if there were a significant problem. An analytical analysis using two-dimensional model test results and correlation with underwater explosion wave predictions indicated a potential danger to the dam and reservoir users.

To more accurately define the wave effects which could be caused by potential landslides in Libby Reservoir, a three-dimensional undistorted hydraulic model (fig. 1) was constructed at the U. S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi. The model was constructed at a linear scale of 1:120, and its purpose was to determine the magnitude of wave heights, runup, and overtopping of the dam for four potential landslides. These potential landslides were located from 160 to

*Fig. 1. General view of Libby Reservoir landslide model just prior to a simulated landslide 700 ft upstream of dam*

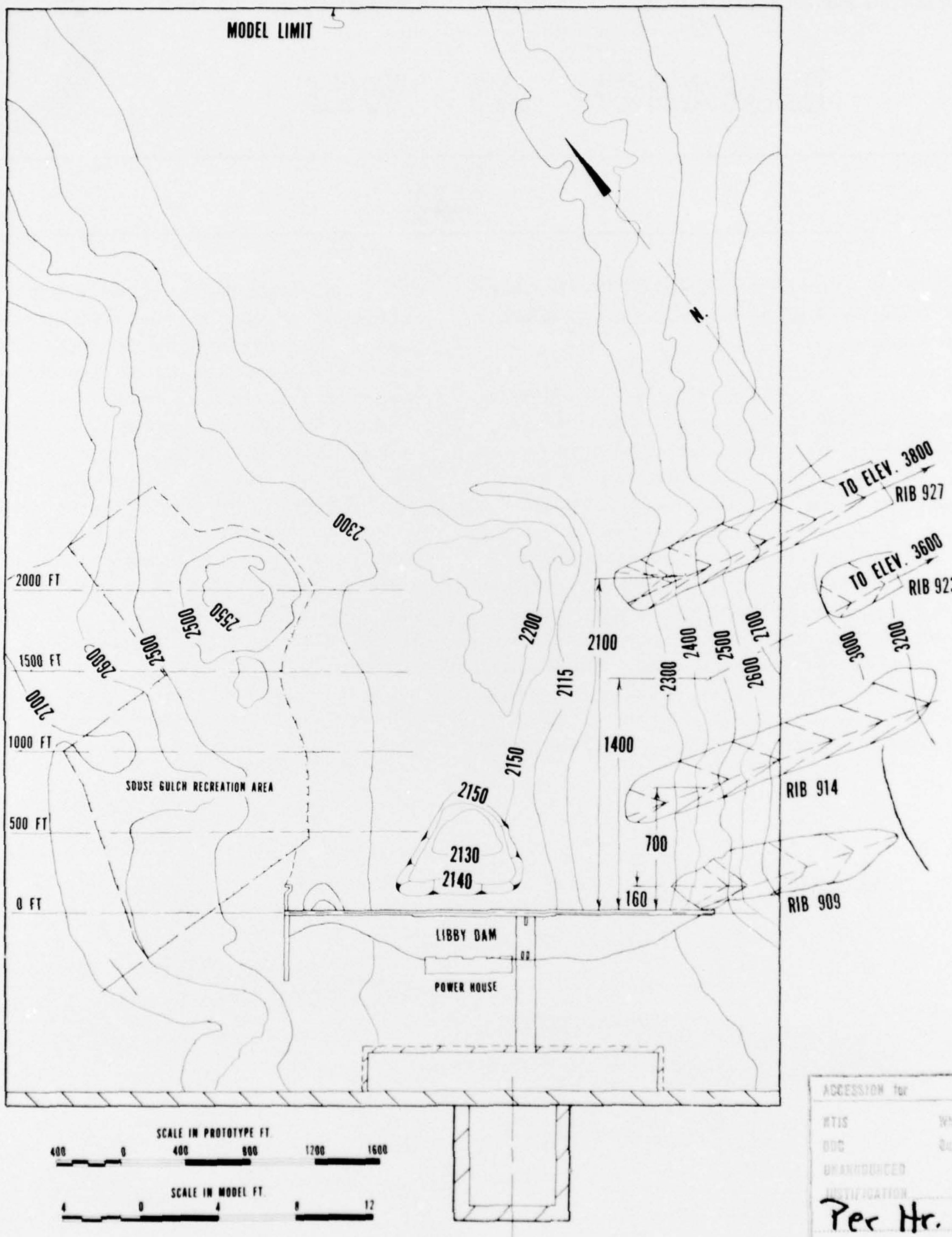


*Fig. 2. Libby Reservoir model layout*

2100 ft upstream of the dam and contained potential landslide volumes of about 900,000 to 4,750,000 cu yd. The model, fig. 2, reproduced an area extending about 1 mile upstream of the dam and about 1200 ft downstream of the dam. The maximum elevation reproduced in the model was elevation 2700 ft msl, with an adjustable mechanical inclined plane to support the landslide material above elevation 2700. The model landslide material consisted of 1/18-cu-ft bags (approximately 60 by 40 by 60 ft, prototype) of iron ore and lead mixed to reproduce the correct land mass density. These bags were hand stacked up the inclined plane slope to obtain the correct distribution, held in place mechanically, and then released to slide into the model by gravity. (Fig. 1 shows the model just prior to a slide approximately 700 ft upstream of the dam.) A few tests were also conducted with gravel and concrete cubes as the landslide material, representing a debris slide, for comparison with results of the bag tests.

Results of the model study have shown the wave heights and runup to be expected at various reservoir pool elevations and have also been helpful in determining the effects of suggested corrective measures for reducing wave heights to an acceptable level. Corrective measures proposed by the sponsoring Seattle District consisted of (1) use of tendons to secure the potential landslide material to the slopes, (2) excavation of the potential landslide material from the slopes, (3) buttressing of the toe of the potential landslide areas to prevent sliding, and (4) installation of a wave trap at the right abutment of the dam in conjunction with item 3 to prevent excessive wave runup on the west bank and thus prevent water from running around the west end of the dam.

General results of the model study to date show that the wave heights resulting from a landslide are critically dependent on the speed of the slide and less sensitive to the alignment and dispersion of the slide.

## RECYCLING OF WASTE CONCRETE,

*by A. D. Buck, Concrete Laboratory*

Metal, glass, paper, and other forms of solid waste are being recycled. Why not portland-cement concrete? Recycling of waste concrete would be especially advantageous today because (1) supplies of mineral aggregates are becoming exhausted in many areas (over 600,000,000 tons of aggregate are required annually in the United States for highway construction alone), and (2) waste concrete removed during demolition of obsolete concrete structures requires disposal.

A study performed in the Concrete Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, has shown that crushed waste concrete can be successfully used as concrete aggregate. Detailed results of that study are given in WES Miscellaneous Paper C-72-14, and a technical paper summarizing them is scheduled to be given at the January 1973 meeting of the Highway Research Board in Washington, D. C.

At the WES, several large fragments of a 6-in.-thick pavement that was being removed and a large unreinforced concrete flexural test specimen were salvaged. The pavement was about eight years old and had been placed using ready-mixed air-entrained concrete of nominal 3000-psi compressive strength made with natural siliceous aggregates of 1-in. maximum size. The flexural test beam contained 3-in. maximum size crushed limestone coarse aggregate and natural siliceous sand fine aggregate and was 9-1/2 months old when discarded and recycled. The waste concrete was crushed to 3/4-in. maximum size.

Samples of chert gravel, natural sand, and crushed limestone similar to those used in the waste concrete were used in control mixtures made in parallel with the crushed waste concrete in the study. Five concrete mixtures were prepared which contained the following combinations of coarse and fine aggregates:

| Coarse Aggregate | Fine Aggregate |
|---|---|
| Chert gravel | Natural sand |
| Crushed chert gravel concrete | Natural sand |
| Crushed chert gravel concrete | Crushed chert gravel concrete |
| Limestone | Natural sand |
| Crushed limestone aggregate concrete | Natural sand |

All concrete mixtures had a water-cement ratio of 0.49 by weight, an air content of 6 ± 1/2 percent, and a slump of 2-1/2 ± 1/2 in.

The strength development of the mixtures using recycled concrete as aggregate was entirely normal, but the strength levels attained were somewhat lower than those of the control mixtures (fig. 1). The strengths at 180 days of the mixtures with recycled gravel aggregate concrete were 4000 psi with natural sand as fine aggregate and 4500 psi with recycled gravel concrete as fine aggregate as compared to a 180-day strength of 5300 psi for the gravel aggregate control mixture. The mixture with recycled limestone aggregate concrete developed a strength of 4800 psi at 180 days age as compared to 5500 psi for the limestone aggregate control mixture.

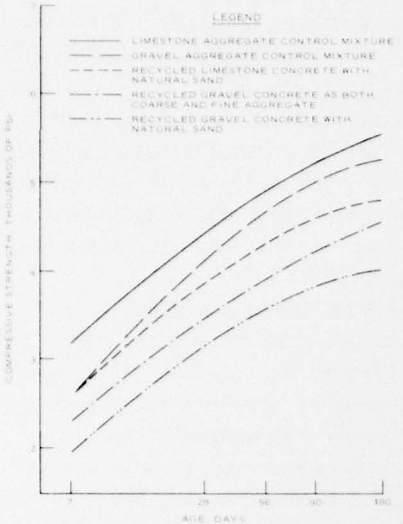


*Fig. 1. Strength versus age for mixtures tested*

The results of tests for resistance to freezing and thawing were significant (fig. 2). The gravel aggregate control concrete was found to have the very low durability factor (DF) characteristic of such concrete (DF = 3). However, the concrete containing recycled chert gravel concrete had significantly improved resistance to freezing and thawing. Recycled gravel concrete with natural sand had a DF of 23, and concrete with recycled gravel concrete as both coarse and fine aggregate had a DF of 28. The limestone aggregate control concrete had a DF of 62, and the mixture with recycled limestone concrete and natural sand had a DF of 45.

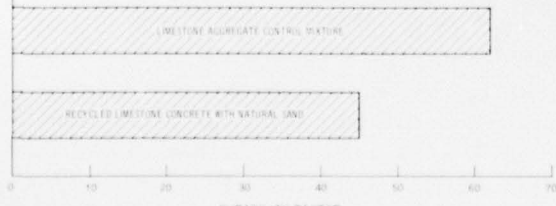


*Fig. 2. Resistance to freezing and thawing for mixtures tested*

Tests were also made for linear coefficient of thermal expansion and length change on continued moist curing, and the results indicated normal behavior for the mixtures containing recycled concrete.

The particles produced by crushing the waste concrete were of normal shape for crushed material. Their absorption was higher and their specific gravity lower than those of the nonrecycled aggregate materials as indicated below:

| | Bulk Specific Gravity, Saturated Surface Dry | Absorption % |
|---|---|---|
| Chert gravel | 2.52 | 2.6 |
| Crushed chert gravel concrete coarse aggregate | 2.43 | 4.1 |
| mestone | 2.67 | 0.8 |
| ushed limestone concrete | 2.52 | 2.6 |
| tural sand | 2.63 | 0.4 |
| Crushed chert gravel concrete fine aggregate | 2.34 | 8.3 |

The recycling of concrete to provide aggregate for portland-cement concrete does not appear to have been the subject of previous research in the USA. One report of research in the USSR in 1946 was located. Results of the present WES study are in general agreement with those reported from the Soviet work.

Future studies of the recycling of concrete should concern situations in which waste concrete of low quality, due either to initially high water content or to subsequent deterioration, is considered as a source of recycled aggregates for high-strength concrete. Additional work on the separation and salvage for recycling of reinforcing or prestressing steel from waste reinforced or prestressed concrete and on separation of contaminants such as gypsum plaster from building rubble would also be desirable.

This preliminary work suggests that recycling of waste concrete is a promising source of aggregate for portland-cement concrete construction as well as being a means of disposal of a significant amount of solid waste.

*Engineering and Scientific Research at WES* is published by the Waterways Experiment Station (WES), Vicksburg, Mississippi, to acquaint U. S. Government agencies and the research community in general with the many-faceted types of engineering and scientific activities currently being conducted at WES. Inquiries with regard to any of the reported specific subjects will be welcomed, and should be addressed to respective authors, U. S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, Mississippi 39180.