Shake Table Studies of Soil-Abutment-Structure Interaction in Skewed Bridges

In an earthquake event, abutment soil failure in skewed bridge leads to rotation of the abutment wall and uneven soil pressure.

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TITLE:
Soil-Abutment-Structure Interaction in Skewed Bridges

SUBHEAD:
Shake tables studies were performed on large-scale test models to investigate the skew angle effect on soil-abutment seismic response.

WHAT WAS THE NEED?
Skewed abutments are vulnerable to high velocity pulse motions due to the induced large residual displacements. Skew angle significantly affects the distribution of soil pressure behind the abutment and, therefore, influences the mobilized passive resistance of the backfill soil. The current Seismic Design Criteria of the California Department of Transportation (Caltrans) does not include any special consideration for the skew angle effect on the passive capacity of soil-abutment systems. Previous experiments on skewed abutments were undertaken on abutments that were restrained against rotation with prescribed uniform displacements under static conditions. Furthermore, the effects of dynamic earthquake forces, abutment rotation, and impact on the abutment wall were not simulated because the tests were static.

WHAT WAS OUR GOAL?
The objective of the study was to investigate experimentally and analytically the effect of skew angle on the soil-abutment response under realistic dynamic earthquake loading and develop recommendations on modeling of skewed abutments for application in bridge seismic design.

WHAT DID WE DO?
The experimental study investigated the soil-abutment-structure interaction in skewed bridges under dynamic loading based on shake table tests at the University of Nevada, Reno. Three 5.5-ft high abutment walls with three skew angles of 0°, 30°, and 45° with a projected width of 10 ft in the direction of motion were tested. The abutment walls were impacted by a bridge superstructure and pushed in the longitudinal direction of the bridge into a 25 ft long by 19 ft wide engineered backfill soil embankment in a stationary timber box. The abutment walls were free to rotate to simulate bridge abutments realistically. A concrete bridge block supported on elastomeric bearings on a shake table represented the superstructure, while the bearings simulated the stiffness of the substructure. The 1994 Northridge Sylmar earthquake record was applied by the shake table with successively increasing amplitudes. Different types of transducers were used to monitor the bridge block and the abutment response under the simulated dynamic loading.

Analytical studies were performed by developing FLAC3D models of the shake table tests in the current study. The analytical models simulated the abutment wall and backfill under the static uniform and non-uniform displacement loading on the wall.

WHAT WAS THE OUTCOME?
The experiments verified that skewed bridges tend to rotate in the direction of reducing the skew angle. This corresponds to impacting abutment at the obtuse corner and unseating of superstructure at the acute corner. The test results showed that the passive capacity, heaves, and accelerations of soil were reduced by increasing the skew angle although the abutment wall width increased when a higher skew was simulated. The distribution of backfill pressure across the abutment was primarily dependent on the direction of the abutment wall rotation while the maximum pressure, heaves, and accelerations occurred at the obtuse corner of the bridge block.

Results from the analytical studies indicated that the backfill passive capacity was reduced when the abutment rotation was accounted for. The displacement contours from the analytical models that simulated the abutment wall rotation were similar to those obtained in the shake table tests. Design recommendations were developed by evaluating the most recent available models estimating the passive force-displacement relationships of the abutments considering the effect of skew.

WHAT IS THE BENEFIT?
The research helped identify the predominant parameters affecting the backfill soil passive resistance due to the skew angle variations such as abutment rotation, impact on the abutment wall and dynamic earthquake effects. The seismic behavior of skewed abutments under realistic earthquake loading can be incorporated in bridge design procedures based on the verification of the experimental and analytical results in this research. The proposed skewed 3D factor could be used in combination with the Hyperbolic Force Displacement (HFD) formulation to simulate the force-displacement relationship of backfill soil in skewed bridges.

LEARN MORE
To view the completed report:
Test model in the 0° skew case

Test model in the 30° skew case

Test model in the 45° skew case

| Run 2 – 50% Sylmar | Run 3 – 75% Sylmar |
Cracks patterns of backfill soil surface for the 0° skew test

Run 6 – 150% Sylmar
Run 7 – 150% Sylmar

Run 2 – 50% Sylmar
Run 3 – 125% Sylmar

Run 4 – 150% Sylmar
Run 5 – 200% Sylmar

Cracks patterns of backfill soil surface for the 30° skew test
Run 2 – 50% Sylmar
Run 3 – 125% Sylmar

Run 4 – 150% Sylmar
Run 5 – 200% Sylmar

Cracks patterns of backfill soil surface for the 45° skew test