Shrinkage and Temperature Forces in Frame Piers

tech transfer summary

Appropriate design strategies for frame piers can ensure their satisfactory performance against shrinkage and temperature effects while maintaining their construction cost advantages.

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RESEARCH PROJECT TITLE
Shrinkage and Temperature Forces in Frame Piers

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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Background

Frame piers, also known as multi-column piers, are a popular type of bridge pier composed of columns that support a cap beam. A frame pier is often the most economical alternative when piers do not need to be placed in water or designed for vehicular collisions.

Problem Statement

Some analyses characterize certain frame pier geometries, such as long frame piers, as being susceptible to forces caused by temperature and shrinkage effects. Designing frame piers according to such analyses may diminish the economic benefits of using this type of pier.

However, these design methodologies often do not fully consider the time-dependent behavior of concrete and the potential consequences of thermal and shrinkage-induced effects, which pose questions about the adequacy of the current set of design requirements for frame piers.

Research Goal and Objectives

This study aimed to accurately estimate the forces imposed on frame piers by temperature and shrinkage effects and provide guidance on designing for such forces. Specific objectives were as follows:

- Develop a numerical model to systematically capture the behavior of frame piers subjected to shrinkage and temperature effects
- Identify the most critical factors that make a frame pier susceptible to shrinkage and temperature effects
- Investigate the ability of various metrics to predict the susceptibility of frame piers to temperature and shrinkage effects

Frame pier in Sioux City, Iowa

Research Description

To determine the temperature and shrinkage effects on frame piers in Iowa, a variety of frame piers were selected for visual inspection or a review of historical inspection reports based on their expected susceptibility to temperature and shrinkage effects.

A set of finite element (FE) models capable of simulating shrinkage strain, creep strain, thermal strain, strength development of concrete, and nonlinear behavior of concrete were also developed and calibrated using experimental test results from the literature.

To further study the magnitude and progression of temperature and shrinkage effects and to validate the FE models, field data were collected from two bridges instrumented at the time of construction: the 418 Woodbury bridge in Sioux City, Iowa, and the 318 Scott bridge in Davenport, Iowa.

The process of frame pier casting was investigated to determine its effect on the magnitude of forces due to temperature and shrinkage. A series of parametric studies was then conducted to investigate the effects of column stiffness, frame length, and bay length on the behavior of frame piers subjected to temperature and shrinkage effects.

Instrumented frame pier of the 418 Woodbury bridge

Instrumented frame pier of the 318 Scott bridge

Various frame pier geometries were analyzed using the validated FE models to identify the most susceptible geometries. The results of these three-dimensional (3D) nonlinear analyses were compared with those from two-dimensional (2D) linear elastic models that simplified the assessment process.

Key Findings

- Frame piers cast in Iowa on warm summer days, particularly in June and July, experience the most demand from temperature and shrinkage effects compared to frame piers cast at other times of the year.
- Frame piers with nonuniform columns, such as those with large exterior columns or varying column heights, were not found to be more susceptible to temperature and shrinkage effects than piers with uniform columns.
- Bay length was found to have a negligible effect on the susceptibility of frame piers to temperature and shrinkage effects.
- The most critical factors affecting the response of frame piers to temperature and shrinkage effects were found to be column stiffness, length of the cap beam, and flexural stiffness of the cap beam. Column stiffness had the greatest impact on susceptibility.
- Basic susceptibility metrics, such as the length of the frame and the length-to-height ratio of the frame, were found to be not accurate enough in predicting susceptibility.
- Accurate susceptibility metrics must account for column stiffness and column restraint.

Implementation Readiness and Benefits

Developing appropriate design strategies for frame piers is essential to ensuring these piers' satisfactory performance, particularly considering that they may be subjected to relatively large shrinkage and temperature forces during their service lives.

The models developed in this research adequately simulated the effects of temperature and shrinkage and identified the frame piers most susceptible to these effects. Furthermore, the metrics identified in this study and a simplified 2D analysis can now be utilized during design to help predict the susceptibility of frame piers to temperature and shrinkage effects.

Overall, the results of this study have led to more informed design guidance for frame piers in Iowa and beyond. The developed models can help predict the susceptibility of frame piers to temperature and shrinkage effects, thus preventing underdesign or overdesign of this important category of piers.