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EFFECT OF SHEAR BANDING ON BRIDGES EQUIPPED WITH SEISMIC ISOLATION PADS

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Abstract

In earthquake-prone regions, engineers frequently install seismic isolation pads between the cap beams and girders of a bridge, or between the box girders and piers, to mitigate the effects of ground vibrations by the increase of the damping ratio and the vibration period. However, ground vibrations are a secondary effect of tectonic earthquakes, contributing less than 10% of the total seismic energy. The primary effect is shear banding, which accounts for more than 90% of the energy during such events. This study identifies three critical findings: (1) Traditional design approaches for bridge isolation pads primarily address the secondary effects of tectonic earthquakes, neglecting the predominant shear banding effect; (2) Isolation pads are prone to failure under shear banding; (3) These pads are suitable only for bridges located in regions with negligible shear banding effects. Consequently, this paper advocates for updated seismic design specifications for bridges that consider both shear banding and ground vibration effects to ensure the integrity of isolation pads during tectonic earthquakes.

Keywords: seismic isolation pads, shear banding, ground vibrations, bridge.

Introduction

Figures 1 through 3 depict a land bridge on Highway 86 in Tainan, Taiwan, comprising a caisson foundation, piers, box girders, and decks. The majority of box girders are directly placed atop pier caps, while seismic isolation pads are installed between some girders and piers. Prior to the 1999 Jiji earthquake, seismic design specifications for bridges (Ministry of Transportation and Communication, R.O.C., 2019) allowed the use of isolation pads to mitigate ground vibrations transmitted to girders and decks, thereby enhancing damping and extending vibration periods, which in turn reduced seismic design demands.

Figure 1. Land bridge on Highway Tai-86 in Tainan, Taiwan.

(a) Longitudinal view of the bridge.

(b) Transverse view of the bridge.

Figure 2. Box girders placed directly atop the bridge piers.

Figure 3. Seismic isolation pad positioned between the bridge pier and the box girder.

There are five primary types of earthquakes: tectonic, volcanic, collapse, reservoir-induced, and explosion-induced (China Earthquake Disaster Prevention Center, 2006; Coffey, 2019; Hsu, 2018). Among these, tectonic earthquakes—especially those with magnitudes greater than M6.0—are the most destructive to bridges. The shear banding effect is the dominant seismic effect in tectonic earthquakes, comprising over 90% of the total energy, while ground vibrations constitute a minor, secondary effect, contributing less than 10% (Hsu, 2018). Given that current bridge seismic design specifications primarily address the secondary ground vibration effects, bridges equipped with seismic isolation pads may resist ground vibrations but remain vulnerable to the shear banding effect.

Given the lack of existing literature on the failure of bridges equipped with seismic isolation pads due to shear banding, this study emphasizes the importance and practical significance of addressing this issue through a series of case studies.

Definition of Earthquake-Resistant Levels for Bridges

Drawing upon Hsu's (2022) definitions of building earthquake-resistant levels, this paper defines three levels of earthquake resistance for bridges:

1) Slightly Non-Earthquake-Resistant: The ground beneath the bridge piers exhibits a mild shear banding effect, with minimal tilting and uplift.
2) Moderately Non-Earthquake-Resistant: The ground beneath the bridge piers shows a moderate shear banding effect, with noticeable tilting, uplift, and moderate cracking.
3) Highly Non-Earthquake-Resistant: The ground beneath the bridge piers demonstrates a significant shear banding effect, with pronounced tilting, uplift, and severe cracking.

Case Studies

1) Over-squeezing and Fracture of the Land Bridge Deck Without Isolation Pads Under Ground Vibration

During the 1999 Jijii earthquake, a land bridge without isolation pads, unaffected by shear banding but subjected to ground vibrations, retained its box girders atop the piers (Figure 4). However, the absence of sufficient expansion joints between adjacent box girders led to mutual compression during the earthquake, resulting in fractures (Figure 5).

Figure 4. Absence of shear banding on the ground adjacent to the piers of the land bridge without isolation pads.

2) The Impact of Isolation Pads on the Lateral Movement of Bridge Decks and Girders

Before the Jiji earthquake, the lateral distance between decks of adjacent box-girder bridges was minimal (Figure 5). Post-earthquake, bridges without isolation pads retained this distance, whereas bridges with isolation pads experienced a lateral displacement of up to 55 cm (Figure 6), leading to an uneven gap and road bending (Figure 7).

Figure 5. Fracture of the box girders on two adjacent land bridges without seismic isolation pads, resulting from excessive mutual compression.

Figure 6. Maximum lateral displacement of 55 cm in the bridge deck and box girders of the left bridge equipped with seismic isolation pads, relative to the corresponding elements of the right bridge.

Figure 7. The uneven opening depicted in Figure 6, which leads to road surface bending on the left.

3) The Effect of Shear Failure of Isolation Pads on Lateral Bridge Movement

Shear failure of the isolation pads caused a 55 cm lateral displacement of the box girder and deck relative to the pier center (Figure 8). This displacement induced a severe eccentric load on the pier, resulting in tilting and fracturing under excessive flexural shear forces (Figure 9).

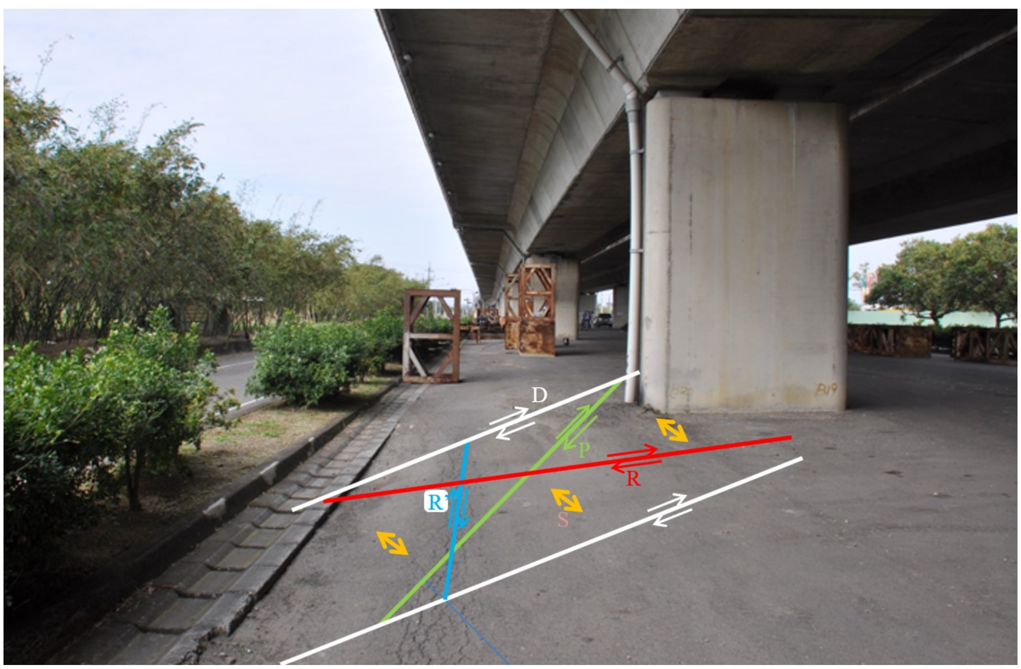
Figure 8. Shear failure of the isolation pad, causing the bridge deck to shift 55 cm to the left relative to the bridge piers.

Figure 9. Tilting and failure of the piers of Wu Creek Bridge during the 921 Jiji Earthquake (National Center for Research on Earthquake Engineering, 2020).

4) Shear Banding Near Pier Columns and Its Impact

Shear failure of the isolation pads corresponded with shear banding of the ground near the bridge pier, attributed to shear textures such as principal displacement shear (D), thrust shear (P), Riedel shear ®, conjugate Riedel shear (R'), and compression texture (S) (Figure 10). On-site investigations confirmed the presence of these shear textures near the piers with lateral displacements, indicating a moderate shear banding effect. This effect induced the shear failure of isolation pads and the significant lateral displacement of the bridge deck and box girders, up to 55 cm.

(a) Before illustrating shear textures.



(b) After illustrating shear textures.

Figure 10. Shear banding of the ground near the bridge pier, corresponding to the shear failure of the seismic isolation pad.

Conclusions and Recommendations

In seismic regions, bridges are commonly equipped with isolation pads to reduce ground vibration effects by enhancing damping and extending vibration periods. However, the primary effect of tectonic earthquakes is shear banding, not ground vibrations. This study reveals that:

1. Current seismic design approaches for bridge isolation pads focus on ground vibration effects, overlooking shear banding.
2. Isolation pads are susceptible to shear failure under shear banding.
3. Existing seismic design specifications are applicable only in areas with minimal shear banding.

To ensure the structural integrity of bridges, it is recommended that seismic design specifications be revised to address both shear banding and ground vibration effects, thereby preventing isolation pad failure and associated bridge damage during tectonic earthquakes.

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