

Rollover stability of precast, prestressed concrete bridge girders with flexible bearings

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- Precast, prestressed concrete bridge girders have become longer, increasing the likelihood of a stability failure.
- An experimental study on the rollover behavior of a 100 ft long (30 m) PCI BT-54 prestressed concrete bridge girder and a nonlinear analysis showed a high sensitivity to the end support conditions.
- The findings indicate that ensuring the flatness of the bottom flange and using wider bearing pads increase stability.

The spans of precast, prestressed concrete bridge girders have become longer for reasons of economy. Improvements in concrete strength, strand diameter, and girder fabrication have made this possible. As the spans have increased, so have the depth and slenderness of the girders. Slenderness increases the likelihood of both lateral-torsional and rollover stability failures, which could pose a danger to construction personnel. Furthermore, stability failures of prestressed concrete girders during construction have a detrimental economic effect due to the costs associated with the failure of the girder, the ensuing construction delays, damage to construction equipment, and potential closures of roadways over which the bridge is being constructed.

The collapse of 150 ft long (46 m), 90 in. deep (2300 mm), precast, prestressed concrete bridge girders on I-80 in Pennsylvania in the fall of 2004 emphasized the need to understand the behavior of such girders with respect to stability.¹ The Pennsylvania Department of Transportation investigating team suspected that additional lateral deformation (sweep) in the girders due to nonuniform heating from solar radiation was a contributing factor in the collapse. A larger initial sweep than anticipated would have increased the possibility of a stability failure because

eccentricity of the gravity load would apply an overturning moment to these girders.

In the summer of 2007 during the construction of the Red Mountain Freeway near Power Road in Mesa, Ariz., nine girders collapsed. Oesterle et al.² concluded that the collapse was due to lateral instability of one girder, which caused a progressive collapse of the adjacent eight girders. They attributed the instability to “bearing eccentricity, initial sweep, thermal sweep, creep sweep, and support slope in both the transverse and longitudinal directions.”

Understanding the stability of precast, prestressed concrete bridge girders requires consideration of rollover, which could have been the cause of the collapse of the aforementioned bridge girders in Pennsylvania and Arizona. A rollover failure in this case would result in the girder as a whole tipping over because there were no lateral restraints. When the girder was placed, it was expected to stay in place due to its self-weight and the width of the bottom flange on the bearing pads. However, any eccentricity due to initial sweep or rotation would generate a torsional overturning moment. If it exceeded the resisting moment, the girder could tip over. The restraint against rollover was provided by the couple between the bottom flange and the steel reinforced elastomeric bearing pads at the supports.

Rollover occurs when an overturning moment develops due to imperfections in the girder, imperfections in the support conditions, lateral loads such as wind, nonlinear behavior of the supports, and, in the case where cracking has occurred, nonlinearity in the stiffness properties of the girder. In this research study, rollover was analyzed by considering the lateral bending of the girder and the subsequent equilibrium rather than by lateral-torsional buckling analysis. Some initial research was done on girder rollover by Imper and Laszlo,³ but this work was expanded on by Mast for the case of a hanging girder⁴ and for the case of a girder on elastic supports.⁵ The works by Mast have become the basis of the standard method used to determine potential rollover of bridge girders during transport and placement. The *Precast Prestressed Concrete Design Manual*⁶ based its requirements on Mast’s work and included his examples.

Burgoyne and Stratford⁷ also considered rollover by using an equilibrium methodology similar to Mast’s.⁵ The primary difference was the way in which initial imperfections were considered. Mast included the initial imperfections within the derivation of equilibrium equations; however, Burgoyne and Stratford considered a perfect beam and then determined the stress distribution due to the initial sweep and the tensile stresses at critical locations. If the tensile stresses were large enough to induce cracking, they concluded that the weak-axis flexural stiffness must be reduced.

To better understand rollover of long girders, an experimental study on the rollover stability behavior of a PCI BT-54 with a 100 ft (30 m) span was conducted and the results were compared with a nonlinear analysis. The experimental setup replicated actual bridge erection conditions without temporary bracing for torsional restraint at the end supports. The effects of initial imperfections, including initial sweep, initial rotation, and initial end rotation, were investigated, as well as the effect of bearing pad stiffness and width. The experimental results were compared with a nonlinear analysis¹ and the predicted factor of safety against rollover from Mast.⁵

Experimental setup

The 100 ft (30 m) span PCI BT-54 was prestressed with forty 0.6 in. diameter (15 mm) prestressing strands, each having a jacking force of 43.940 kip (195.47 kN). It was supported to replicate actual bridge end conditions without temporary supports. The girder was placed on 24 in. × 14 in. (610 mm × 360 mm) steel reinforced elastomeric bearing pads (**Fig. 1**). The pads were $2\frac{7}{8}$ in. (73 mm) thick with four internal steel shims. The strong- and weak-axis rotation depended on the stiffness, width, and length of the bearing pads. No bracing or restraints to lateral displacement or rollover were provided.

Vertical, lateral, and torsional displacements, as well as surface strains, were recorded at midspan. Similar displacements were recorded at the supports (**Fig. 2**) to monitor the compressive deformation of the bearing pads. Initial lateral displacements were measured at nine points along the beam at both the top and bottom of the cross section, thus allowing the calculation of initial rotation along the length. Concrete material testing was performed at the time of testing.

Load application

The single concentrated load was applied with a gravity load simulator, an actuator that kept the load vertical, moved laterally with the beam, and did not restrain lateral and torsional deformations. The loading mechanism was designed as a high-capacity version of the original configuration by Yarimci et al.⁸ that was used to test sway frames. The gravity load simulator pulled down on the girder.

Instrumentation

Lateral displacement at midspan was recorded at five locations along the depth of the cross section using string potentiometers. Furthermore, two string potentiometers were used to measure the vertical displacement at each edge of the bottom flange at midspan. Displacement measurements were adjusted due to angle changes of the beams by using the technique described by Stoddard⁹ and modified for flanged cross sections by Hurff.¹ Three string potentiometers



Figure 1. PCI BT-54 rollover stability experimental setup.

at each end monitored the rotation and displacements due to the compressive deformation of the bearing pad so that the relative rotation and girder deformation at midspan could be determined. One string potentiometer measured the lateral shear deformation of the bearing pad. Two potentiometers measured the vertical displacements of the pad on each side. On each face of the girder at midspan, axial strains along the depth of the section were measured using 10 in. long (250 mm) strain gauges made with linear variable differential transformers (LVDTs) (Fig. 3). From the strain profile on the surface of the cross section on each side, the depth and orientation of the neutral axis were determined.

Concrete material properties

Five 6 in. × 12 in. (150 mm × 600 mm) cylinder specimens were tested to determine concrete compressive strength, and five cylinders were tested to determine elastic modulus

at the time of tests per ASTM C33¹⁰ and ASTM C469¹¹, respectively. The mean compressive strength was 12,190 psi (84.05 MPa). Poisson's ratio was 0.22, and the modulus of elasticity was 4470 ksi (30.8 GPa).

Initial imperfections, particularly initial rotation, were noted as contributing factors in the girder collapses in Pennsylvania¹ and Arizona.² Furthermore, initial imperfections including end rotation would be detrimental to the factor of safety against rollover using the analytical method by Mast.⁵ Therefore, determining the effect of initial imperfections on the rollover stability was an objective of the study. The measured initial sweep was 1.94 in. (49.3 mm) at the top flange and 1.48 in. (37.6 mm) at the bottom flange. A level, flat bearing was used for one test. In a second test, the bearing at each end was sloped 0.05 rad to model the end conditions found for the Arizona collapse.²



Figure 2. Bearing pad vertical displacements were measured at each side of the bottom flange. Note: 1 in. = 25.4 mm.

Experimental results and behavior

Bottom flange bearing flatness

When the PCI BT-54 was first tested with the sloped bearing, loading was halted at 29 kip (129 kN) because the end rotation observed was substantially larger than anticipated. At 29 kip, the end rotation was expected to be on the order of 0.00072 rad; however, the measured end rotation was 0.0042 rad (six times larger than expected). There was a significant lack of flatness of the bottom flange of the girder (**Fig. 4**). The lack of flatness allowed the girder to roll on the elastomeric bearing pad as opposed to having the full width of the bottom flange create a resisting moment. The *Tolerance Manual for Precast and Prestressed Concrete Construction*¹² does not give a specific tolerance for the flatness of the bottom flange; however, the tolerance for the local smoothness of any surface is $\frac{1}{4}$ in. (6 mm) over 10 ft (3 m).

Neither the nonlinear geometric analysis¹ nor the rollover analysis⁵ considers the effect of a lack of flatness of the bottom flange. Both analyses require an appropriate prediction of the rotational stiffness provided by the couple between the bottom flange and elastomeric bearing pad. High-modulus epoxy was placed on the bottom of the girder to provide a flat bearing surface for further testing.

Figure 5 compares the rollover end rotation of the first loading and the second loading. With a flat bottom flange, the end rotation at approximately 100 kip (445 kN) was equivalent to the end rotation at 29 kip (129 kN) for the experiment with rounded bottom flanges. Therefore, ensuring a flat bottom flange at the supports is important for providing rollover resistance.

Furthermore, the effect of the deviation from flatness of the bottom flange was apparent when the girder was first placed on the supports; the girder rotated 0.015 rad in ad-

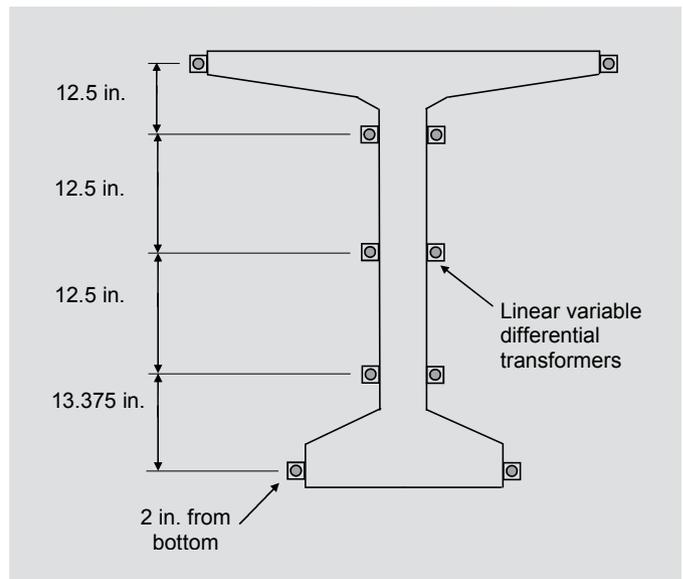


Figure 3. Linear variable differential transformers on PCI BT-54 measure longitudinal strains at these midspan locations. Note: 1 in. = 25.4 mm.

dition to the initial end support slope of 0.05 rad. After the retrofit to provide a flat bottom flange and resetting of the girder, there was a negligible rotation under the self-weight of the girder. **Figure 5** shows the detrimental effect that a rounded bottom flange can have on the stability. Further research is needed to quantify the behavior.

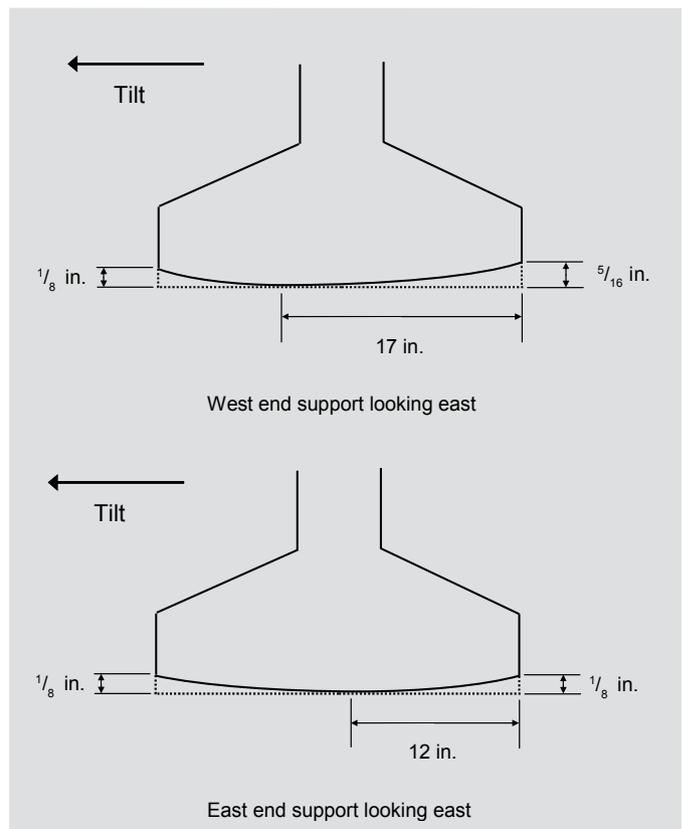


Figure 4. Bottom flange profiles for west-end support and east-end support show the lack of flatness of the BT-54 flange. Note: 1 in. = 25.4 mm.

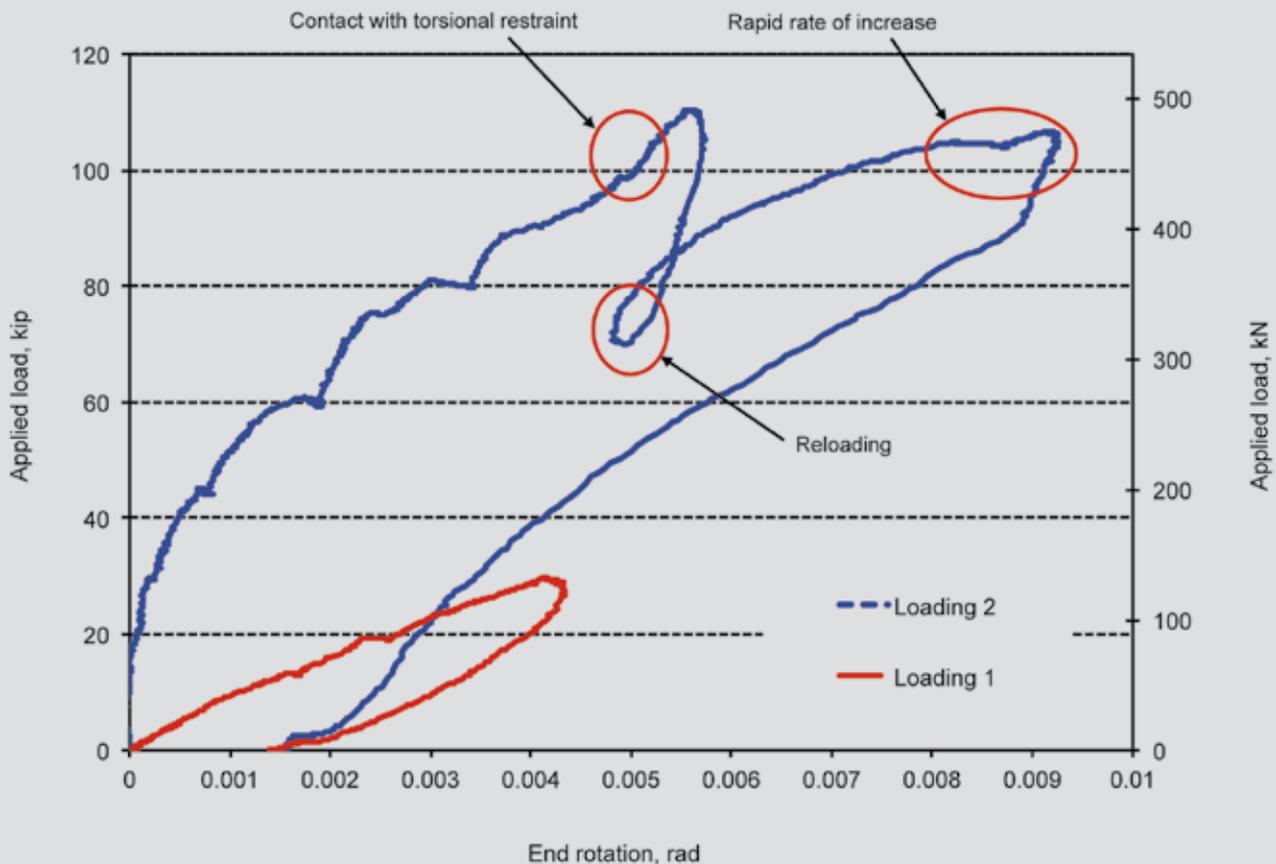


Figure 5. The rollover end rotations for loading 1 were larger at lower loads than for loading 2 due to the lack of flatness of the bottom flange during the loading 1 test.

Rollover stability experimental results

During the second loading at approximately 80 kip (360 kN), uplift of one side of the bottom flange began at both supports; however, the load could still be increased without unstable behavior. At approximately 100 kip (440 kN), the top flange of the girder at the supports contacted the restraints at the end of the girder that had been installed for safety. Lateral displacements of the top flange at the supports had reached 0.6 in. (15 mm) with an additional end rotation of 0.0055 rad. At that point, which is noted in **Fig. 5** and **6**, the load was reduced to 70 kip (310 kN) to verify the safety of the setup, the restraints were set back to permit up to 1 in. (25 mm) of lateral displacement, and loading was resumed.

Figure 6 shows the load-versus-rotation curves at midspan and ends. It is apparent that the slope of the curve was similar between initial loading and reloading between 70 kip and 100 kip (310 kN to 440 kN). However, the reloading curve was offset from the initial loading curve due to residual deformation and rotation, primarily at the supports. When the load reached 104 kip (463 kN), the lateral displacement and rotation began to increase rapidly

with little to no increase in load. The midspan rotation was a summation of the end rotation or rigid body rotation and the elastic torsional deformation of the girder along its length. Comparison of the midspan and end rotation shows that more than half of the midspan rotation was due to rigid body rotation as opposed to elastic deformation.

Figure 6 also shows the applied load versus rotation for the control loading, which involved placing the girder on level supports. The control shows almost negligible end rotation. There was rotation at midspan due to the elastic torsional deformation of the girder; however, the magnitude was approximately 50% of that for the test with initially sloped supports. The experiment with level supports was loaded to 123 kip (547 kN), 18% higher than the second loading, with no sign of unstable behavior. That is, initially sloped end supports significantly altered the behavior of the girder and reduced the factor of safety against rollover stability.

Analytical study

Nonlinear analysis

The material and geometric nonlinear analysis¹ was a load-controlled, matrix-based program. Because the program

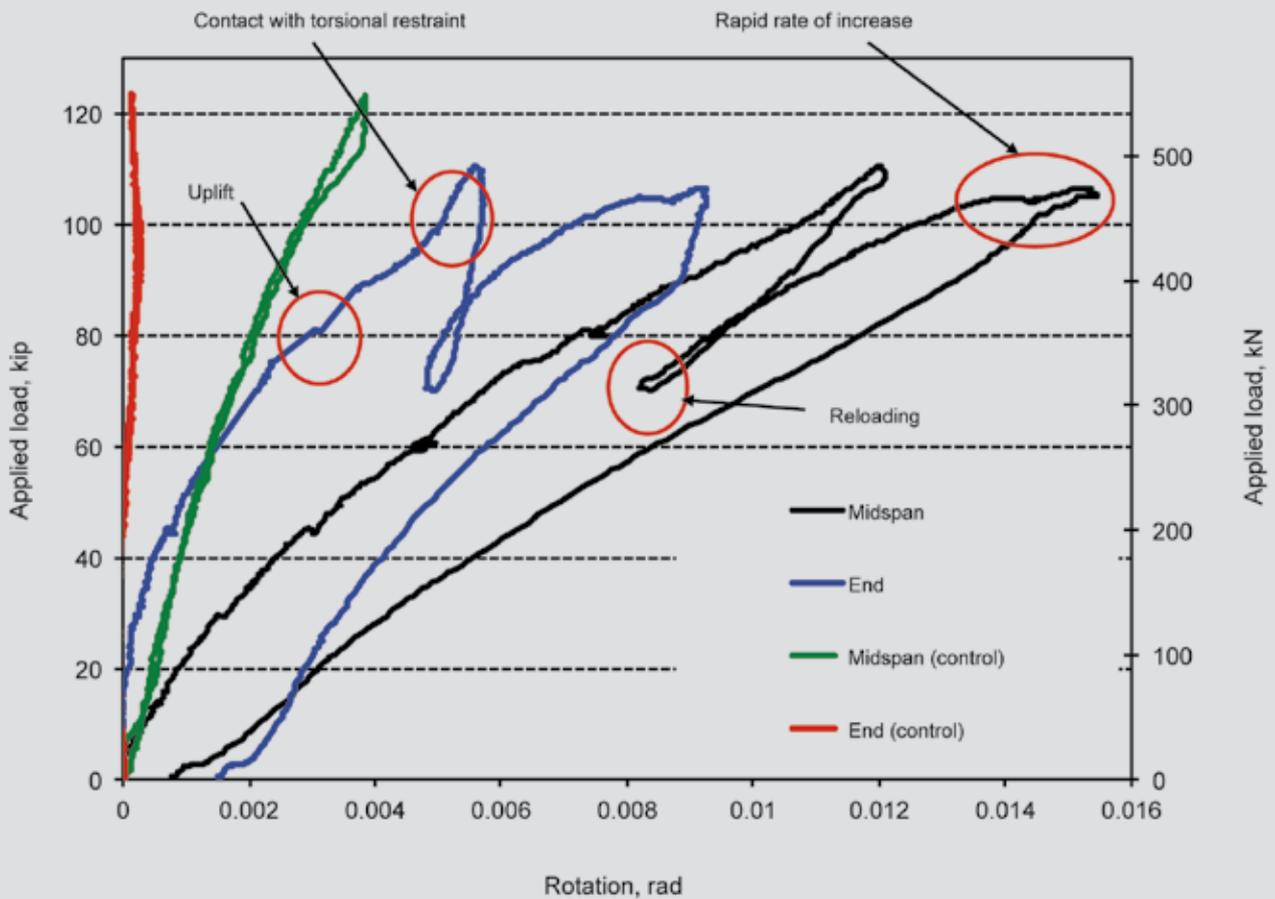


Figure 6. Load versus midspan and end rotation for sloped and level (control) supports.

was load controlled, 100 lb (0.45 kN) load increments were used to obtain accurate results for the nonlinear geometric behavior by applying the load to the deformed shape of the structure for the previous load increment. The material nonlinearity was considered by altering the stiffness properties in the global stiffness matrix at various locations along the beam to consider changes in the modulus and the reduction in stiffness due to cracking at each load increment. Nonlinear material properties were not critical for this case; however, nonlinear geometric behavior was.

Accuracy was determined by running the program at several load increments until convergence was apparent. In the bearing pad model, the vertical load and torque at the ends of the girder were used to determine the vertical and rotational deformation of the bearing pad. The bearing pad model divided the pad into forty-eight 0.5 in. wide (13 mm) strips oriented parallel to the centerline of the girder (Fig. 7). The analysis iterated axial (vertical) deformation and bearing pad rotation until both force and torsional moment equilibrium were satisfied. The forces in each bearing pad strip were determined using a bilinear material representation of the experimentally determined load versus vertical displacement curve. The strips that underwent tensile forces (uplift) were taken as zero force

strips when equilibrium was calculated. Details of the nonlinear analysis procedure are provided by Hurff.¹

To determine the accuracy of the analytical model for predicting the elastic response of the girder, the rigid body rotation of the girder about the supports and the shear deformation of the bearing pad were removed from the raw experimental data (Fig. 8). A similar reduction was performed on the analytical data to give the red dashed line. The nonlinear analysis predicted the elastic response of the girder well (Fig. 8). Furthermore, when the effects of rigid body rotation were removed from the raw data, the unstable behavior that was witnessed was no longer apparent in the data. That suggests that the unstable mechanism was not an unstable deformation behavior such as lateral-torsional buckling but instead was rigid body rotation.

Figure 9 compares the analytical and experimental rotation at midspan, which includes the effect of the rigid body rotation at the supports. The analytical model predicted larger rotations at loads up to 60 kip (270 kN), thus underestimating the rotational stiffness of the bearing pads in that load range. However, at loads higher than 60 kip (270 kN), the analytical model began to overestimate the rotational stiffness provided by the bearing pads. Further-

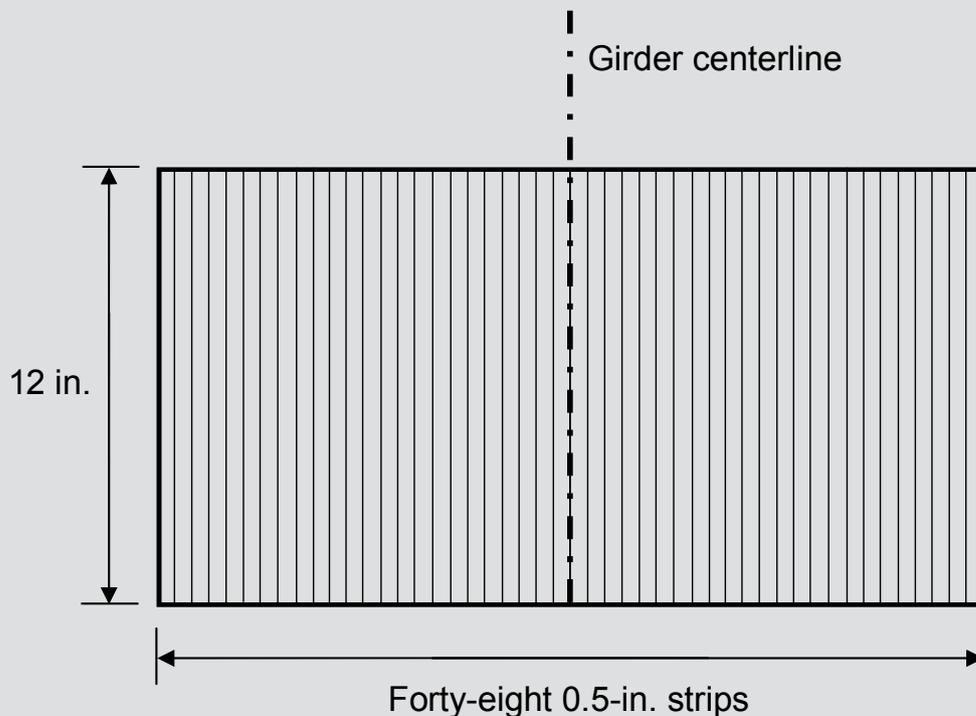


Figure 7. Plan drawing of the bearing pad strip model layout that was used to determine the vertical and rotational deformation of the bearing pad.
 Note: 1 in. = 25.4 mm.

more, the analytical model did not show the full unstable rollover behavior until a load on the order of 180 kip (800 kN) that was 70% higher than the experimental rollover load. The significant difference in the rollover load was due to a significant overprediction of the bearing pad rotational stiffness at loads above 60 kip (270 kN).

The analytical model did not consider the second-order effect due to the lateral shear deformation of the bearing pads that became evident at higher loads. The shear deformation of the bearing pads was about 0.45 in. (11 mm) at the 104 kip (463 kN) load. It was hypothesized that the shear deformation caused a softening of the bearing pad vertical stiffness at the compressed edge of the bearing pad. The strips at the compressed edge of the bearing pad contributed significantly to the calculation of moment equilibrium within the model. The softening effect was not measured experimentally.

Rollover analysis

The method from Mast⁵ for rollover stability of prestressed concrete bridge girders on flexible bearings provided a simple way to calculate the factor of safety against rollover (load required for rollover divided by self-weight). The factor of safety FS against rollover for a girder supported from below is as follows:⁵

$$FS = \frac{c_r}{c_a} = \frac{r(\theta - \alpha)}{z_o\theta + e_i + y\theta}$$

where

c_r = resisting moment arm

c_a = applied moment arm

r = radius of stability

$$= K_\theta/W$$

K_θ = support rotational spring constant

W = weight of girder

θ = roll angle of major axis of beam with respect to vertical

α = tilt angle of support

z_o = theoretical lateral deflection of the center of gravity of the girder due to the full self-weight applied laterally

e_i = initial lateral eccentricity of the center of gravity of the girder

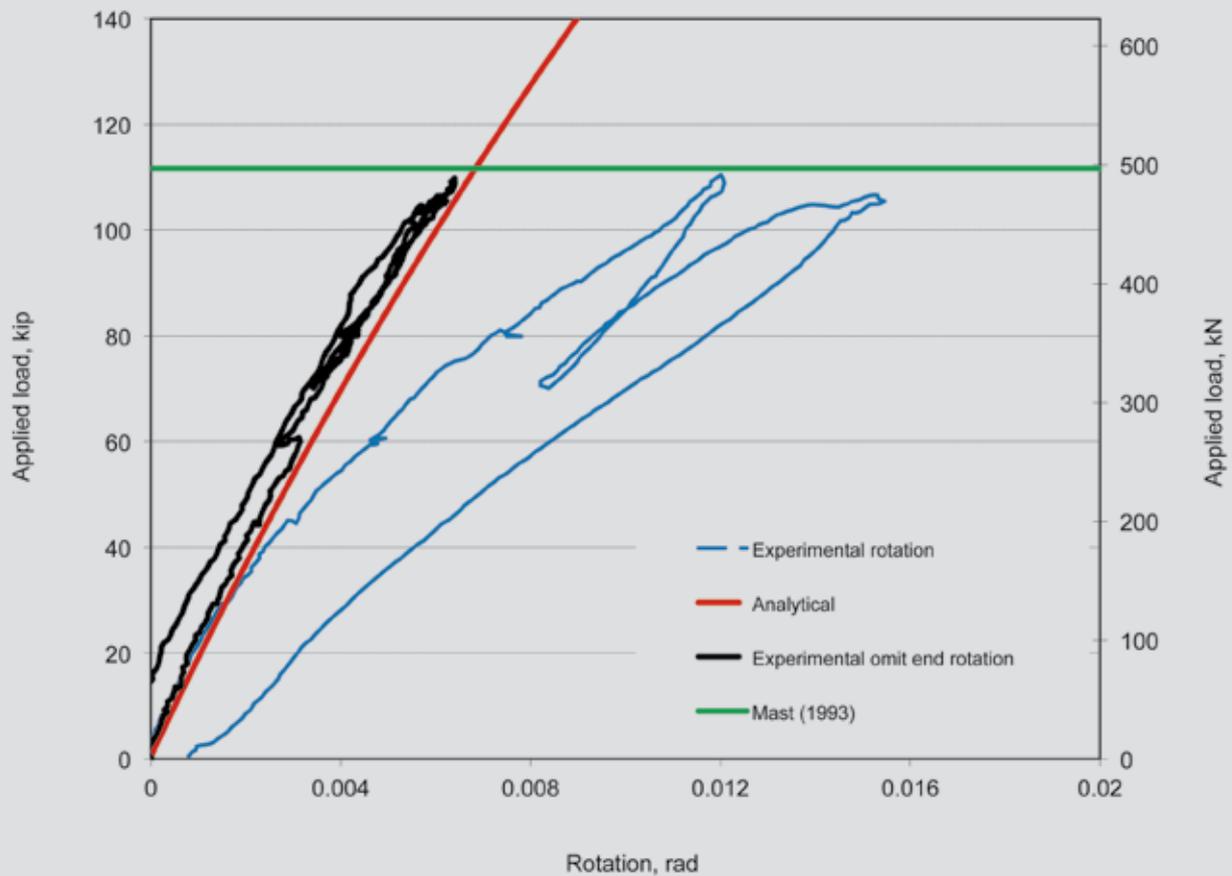


Figure 8. The experimental and analytical load versus midspan rotation shows good correlation between the experimental results and the method by Mast.⁵

y = height of center of gravity of beam above roll axis

The prediction for the rollover load from Mast⁵ for the experimental PCI BT-54 was superimposed on the experimental and analytical data in Fig. 8. The predicted rollover load was 112 kip (497 kN), which showed good correlation to the experimental rollover load of 104 kip (463 kN).

The estimation of the bearing pad rotational stiffness is important because the rollover method by Mast⁵ depends on the assumed rotational stiffness. Mast⁵ emphasizes the effect of rotational stiffness on the rollover stability of a girder. The rotational stiffness can be determined from the axial (vertical) stiffness of the bearing pad. The vertical load–deflection response of the bearing pads (Fig. 10) was measured before the tests. At a vertical load of 34.7 kip (154 kN), equal to one-half the total self-weight of the girder, the tangent vertical stiffness given by the experimental curve was 4573 kip/in. (801 kN/mm). The rotational stiffness was calculated from the vertical stiffness using Yazdani et al.,¹³ resulting in a rotational stiffness of 219,500 kip-in./rad (24,800 kN-m/rad).

The vertical stiffness can be predicted using the American Association of State Highway and Transportation Officials’

AASHTO LRFD Bridge Design Specifications¹⁴ and the specification that the bearing pads must have a shear modulus between 95 psi and 200 psi (0.67 MPa and 1.4 MPa). AASHTO LRFD specifications provide the methodology to calculate the shape factor and compressive modulus of the bearing pad. From these properties, the axial and rotational stiffness can be determined using Yazdani et al.¹³ The AASHTO LRFD specifications technique using a low value of shear modulus of 95 psi (0.67 MPa) resulted in a theoretical vertical stiffness of 7296 kip/in. (1278 kN/mm) and a theoretical rotational stiffness of 350,200 kip-in./rad (39,570 kN-m/rad). The predicted vertical and rotational stiffnesses were 60% greater than the experimentally determined vertical and rotational stiffnesses. Further, if the average shear stiffness of 148 psi (1020 kPa) was used, the predicted vertical and rotational stiffnesses would be 150% greater than the experimental value.

The AASHTO LRFD specifications relations predict the axial stiffness under the service load of the bridge. For our test girder, that would be a reaction of about 122 kip (543 kN). The axial stiffness of the pad under the service load is greater than under just the self-weight of the girder because of the nonlinear behavior of the bearing pad. Therefore, predictions for rollover stability should be

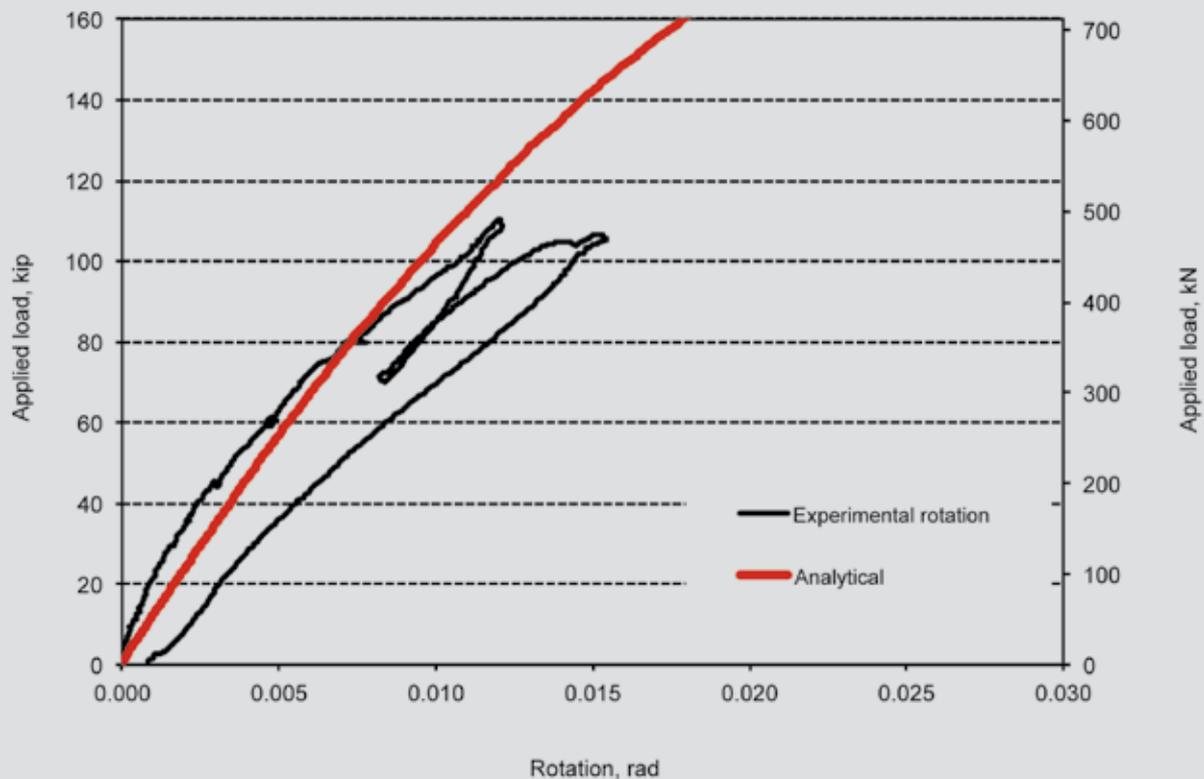


Figure 9. The applied load versus total rotation (girder rotation + end rotation) at midspan shows the deviation between the experimental and analytical results due to the bearing pad deformation.

based on the nonlinear bearing pad stiffness using the self-weight of the girder alone.

The Georgia Department of Transportation determines the axial stiffness of elastomeric bearing pads pursuant to AASHTO Specification M251 *Standard Specification for Plain and Laminated Elastomeric Bridge Bearings*,¹⁵ which specifies loading the bearing pad to the design dead load plus live service load and then measuring the final axial shortening of the bearing pad. To test the performance of the pad based on AASHTO M251, the pad is loaded to 150% of the design service load. Essentially, one load and deformation point is measured; the nonlinear behavior of the bearing pads at lower loads is not considered. For the bearing pads used in the experiments of this study, at a load of 96 kip (356 kN) the experimental vertical stiffness was 9387 kip/in. (1644 kN/mm), resulting in a shear modulus of 122 psi (0.841 MPa). The shear modulus at higher loads was well within the allowable range specified in AASHTO LRFD specifications. However, during the rollover experiment, the maximum load experienced by a single bearing pad was 86 kip (383 kN). Furthermore, the girders that collapsed in Arizona had a self-weight-to-service load ratio of approximately 0.31.

The effect of the width of the bearing pad on the factor of safety against rollover was also analyzed. The bearing pad

used in this study was 24 in. wide (610 mm) (dimension perpendicular to girder longitudinal axis); however, the bearing pads used to support the girders that collapsed in Arizona were only 18 in. (460 mm) wide,² less than the bottom flange width of 26 in. (660 mm). It was calculated that using an 18 in. wide (460 mm) bearing pad as opposed to the 24 in. wide (610 mm) bearing pad for the PCI BT-54 bridge girder of this study would reduce the factor of safety against rollover by 39%.

The analyses and the experiments demonstrated that the bearing pad stiffness parameter should be based on the vertical load of the girders themselves and not on the service load; this lower load results in a significantly lower bearing pad stiffness. Further research should be done to determine the axial and rotational stiffness of bearing pads with applied loads in the range of the self-weight of the girder and to establish a rational factor of safety against rollover. Mast⁵ recommended a factor of safety against rollover of 1.5 based on his experience.

Lateral-torsional buckling

The authors believe that the girder collapses in Pennsylvania and Arizona were due to rollover as opposed to lateral-torsional buckling because the bridge girder cross sections (AASHTO and PCI bulb tees) had stiffness parameters

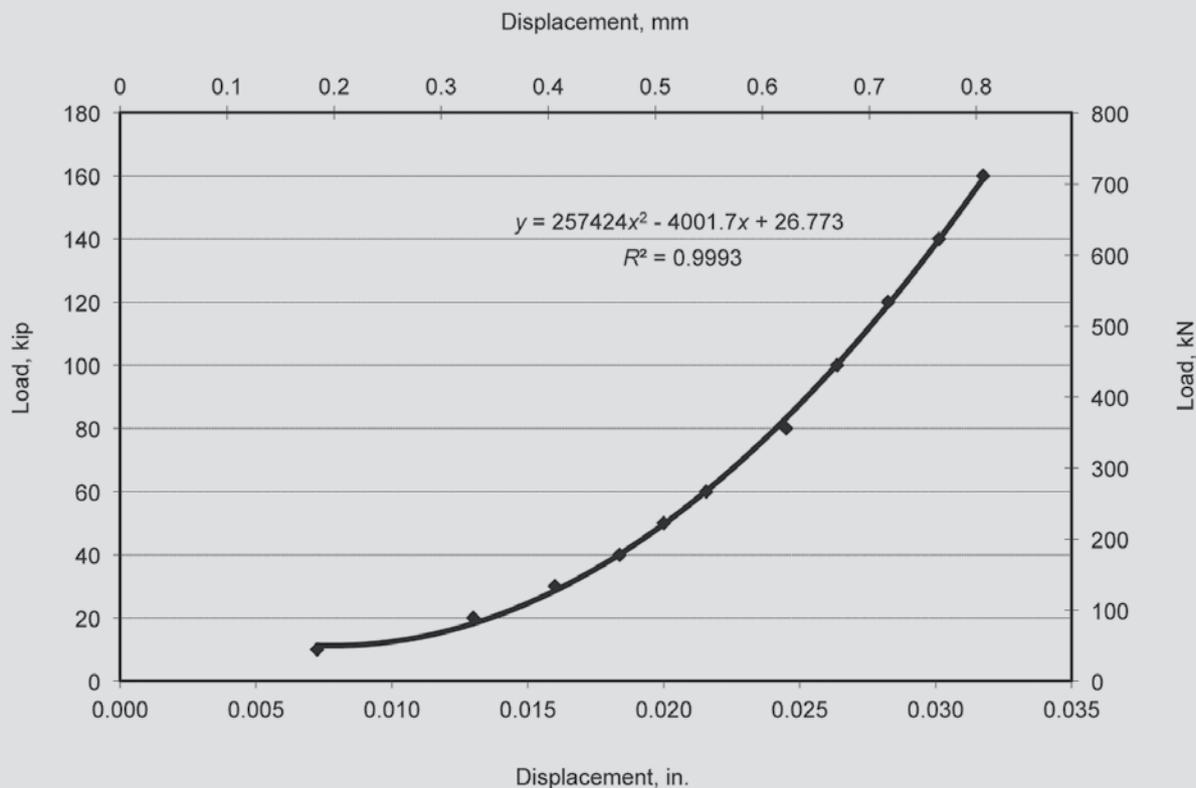


Figure 10. The load versus axial (vertical) displacement of bearing pad with second-order polynomial fit shows the nonlinear nature of the bearing pad deformation.

$\sqrt{EI_y GJ} / L$ (where E is modulus of elasticity, I_y is weak-axis bending moment of inertia, G is the concrete shear modulus, J is torsional stiffness, and L is length) that were sufficiently large to prevent lateral-torsional buckling. Only with a fully cracked bottom flange would the weak-axis bending inertia I_y and torsional stiffness J be low enough to permit buckling. Prestressed concrete bridge girders are designed so that no flexural cracking occurs under the self-weight of the girder. Therefore, the stability of prestressed concrete bridge girders on flexible supports is governed by rollover stability for AASHTO and PCI bulb-tee cross sections as well as other equally stiff shapes.

Conclusion

This paper presented the results of an experimental study on the rollover stability of a PCI BT-54 precast, prestressed concrete bridge girder with a 100 ft (30 m) span. The effect of compressive deformation of the elastomeric bearing pads at the supports was investigated. The results of the experiments were compared with the analytical methodology of Mast⁵ and with a nonlinear material and geometric analysis.¹ The following conclusions and recommendations were made based on the study:

- The initial sweep and rotation imperfections signifi-

cantly affected the load versus lateral displacement and load versus rotation behavior. The rate of increase of lateral displacement and rotation was amplified due to increased initial imperfections, leading to rollover at lower loads than if near zero imperfections were assumed based on allowable tolerances.

- The nonlinear material and geometric analysis results matched well with the experimental load versus lateral displacement and load versus rotation for the PCI BT-54 girder. Although the nonlinear incremental analysis predicted the general trend of the end rotation behavior due to the bearing pad compressive deformation, the assumptions and simplifications used to model the bearing pad led to a predicted rollover load greater than found experimentally.
- The rollover methodology from Mast⁵ accurately predicted the rollover load of the PCI BT-54; therefore, the Mast⁵ technique should continue to be used to predict the factor of safety against rollover failure. However, the procedure depends on the assumed rotational stiffness of the support. Therefore, the actual stiffness of the bearing pad at vertical loads equal to the self-weight of the girder should be used to calculate the pad's rotational stiffness.

- The rollover behavior was sensitive to bearing pad width. Using a wider pad significantly increases the factor of safety against rollover. From rollover analyses using Mast,⁵ the width of the pads should be selected as close as possible to the width of the bottom flange of the prestressed concrete bridge girder (minus the edge chamfers) to maximize stability. For example, the factor of safety against rollover failure for a 100 ft (30 m) PCI BT-54 was 39% lower for an 18 in. wide (460 mm) elastomeric bearing pad than for a 24 in. wide (610 mm) pad.
- Lack of flatness of the bottom flange of a prestressed concrete bridge girder was shown in this research to increase the initial rotation of the girder an additional 0.02 rad that caused a premature rollover failure. One method to ensure a flat bearing surface may be to use an embedded steel bearing plate in the bottom flange.
- Future long-span prestressed concrete bridge girder cross sections should have increased bottom flange widths to increase stability and resistance to rollover failures of girders. Increasing the bottom flange width is the most effective way to change the geometry and increase the factor of safety against rollover of the girder. The weak-axis moment of inertia and the rotational inertia are increased favorably by an increase in the bottom flange width, and the larger bottom flange width allows for a wider bearing pad to be used.
- A prestressed concrete bridge girder should be laterally braced adequately at the supports as soon as possible after the girder is erected. Such bracing will reduce the possibility of rollover failures.

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Notation

c_a = applied moment arm

c_r = resisting moment arm

e_i = initial lateral eccentricity of the center of gravity of the girder

E = concrete elastic modulus

G = shear modulus of concrete

I_y = weak-axis bending moment of inertia

J = torsional stiffness

K_θ = support rotational spring constant

L = length

r = radius of stability = K_θ/W

W = weight of girder

y = height of center of gravity of beam above roll axis

z_o = theoretical lateral deflection of the center of gravity of the girder due to the full self-weight applied laterally

α = tilt angle of support

θ = roll angle of major axis of beam with respect to vertical

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Abstract

Precast, prestressed concrete bridge girders have become longer, increasing the likelihood of a stability failure. Understanding the stability behavior of prestressed concrete bridge girders on flexible supports entails the consideration of the deformation of the girder, the initial imperfections of the girder, the initial support rotation, and the rotational stiffness provided by the bearing pads. An experimental study on the rollover behavior of a 100 ft long (30 m) PCI BT-54 prestressed concrete bridge girder was performed. Qualitative conclusions were derived from the experi-

ments, and a comparison was made to a nonlinear analysis and to the current method for calculating factor of safety against rollover. The experimental and analytical study showed a high sensitivity to the end support conditions. Recommendations were made for increasing the rollover stability of prestressed concrete bridge girders and for values to assume in the modeling of the support conditions and member imperfections when performing stability analyses..

Keywords

Elastomeric bearing pads, flexible bearings, rollover, structural stability.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

Reader comments

Please address any reader comments to journal@pci.org or Precast/Prestressed Concrete Institute, c/o PCI Journal, 200 W. Adams St., Suite 2100, Chicago, IL 60606. ¶