Construction Loadings

Bob McCullouch P.E. Ph.D.

PURDUE UNIVERSITY

Ohio Transportation Engineering Conference

Mark Your Calendar for OTEC 2010
October 19-20, 2010

Register Now!

online event registration
by Regonline

OTEC 2010 Brochure

Session Track Schedule
With links to detailed descriptions of each session

Purdue Breakfast
The University of Purdue will be sponsoring an Alumni Breakfast.
For details, contact Frank O'Hare directly at:
(614) 506-1068 or
fohare@ctconsultants.com

Construction Loadings

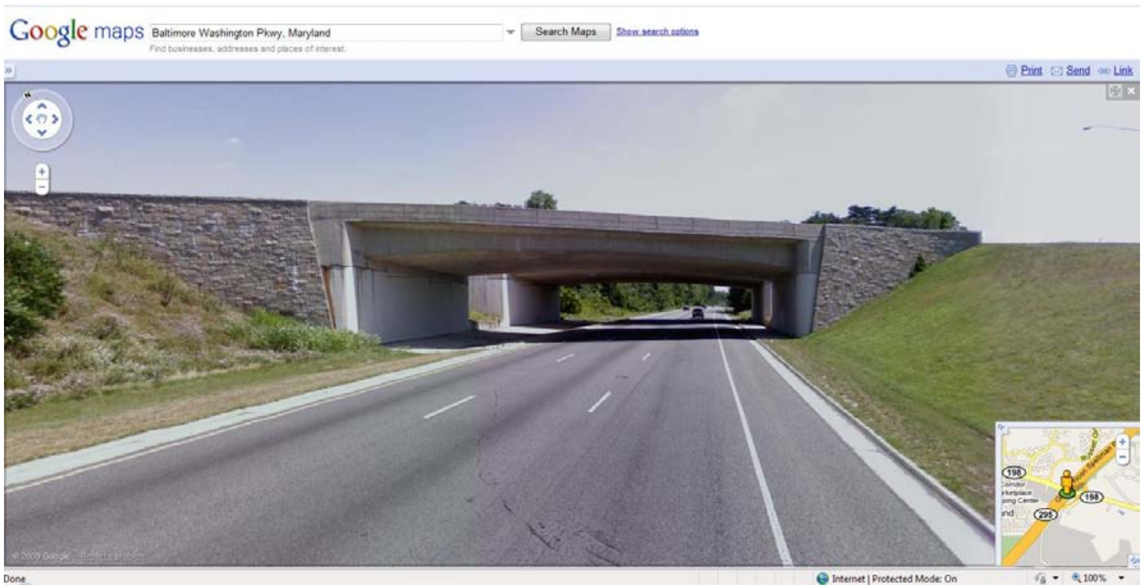
- Construction Perspective
- Design Perspective – Important but not covered

Maryland Bridge

"The collapse in August 1989 of the Route 198 bridge over the Baltimore-Washington Parkway was caused by poorly constructed scaffolding that was built with rusty, deteriorating metal and unapproved parts and materials, federal highway officials said yesterday."

"The approved plans called for screw-shaped jacks capable of handling a load of 25,000 pounds, McCormick said. However, federal investigators found the contractors had used smaller screw jacks with only a 10,000-pound capacity."

-Veronica Jennings, The Washington Post



Hawaii Bridge

Bridge Girder Failure During Construction

Related Capabilities

- » Construction Accidents
- » Special Structures (Bridges, Tanks)

In July of 1996, four construction workers were injured when four 120-foot-long, 60-ton girders supporting an unfinished section of freeway collapsed and fell 15 feet. The collapsed span was part of the elevated section of the new 16-mile H-3 freeway being constructed through the Halawa Valley in Hawaii. Construction was halted immediately after the collapse until the cause of the accident could be determined.

The cause of the accident was not readily apparent—the girders had been in place for over a week and appeared to be stable up to the time of collapse. The general construction contractor retained Exponent to investigate the collapse. Within hours, a team of Exponent engineers arrived in Hawaii to conduct an onsite survey of the damage.

Of immediate concern was whether the bridge collapsed because of a design deficiency or a construction problem. Either failure mode would have severe implications regarding the existing and future construction, so it was paramount that the cause be determined quickly. The Exponent investigation determined that each girder was restrained by a frictional force at the hanger beam end and with pedestal concrete at the hinge end. When thermal expansion occurred in the girders, the friction force limited the amount of expansion that could occur. This caused one girder to buckle laterally, causing a chain reaction in the other girders.

Exponent recommended using a hanger with the capacity to slip, to allow for thermal expansion during construction. Furthermore, Exponent recommended that a temporary system of cross bracing be added during construction, to provide redundant lateral support to the tall, thin precast girders until the bridge deck was in place. These corrective measures allowed construction to resume with minimal delay.

Colorado Bridge

May 2004

Family of three killed.

Causes

- Girder out-of-plumb
  - 4.26^{o} at south abutment
  - 2.33^{o} at center bridge pier
- Temporary bracing, a failure
  - Expansion bolts separated from bridge deck
    - Bolt hole dia. 0.90”
    - Bolt dia. 0.75”
    - Bolts required to be embedded into concrete minimum 3.25”
    - All but 1 bolt embedded into concrete at depths of 1.25” to 2.50”
- Finite element analysis determined cyclic vibrations caused by lateral vibrations and wind loads caused failure

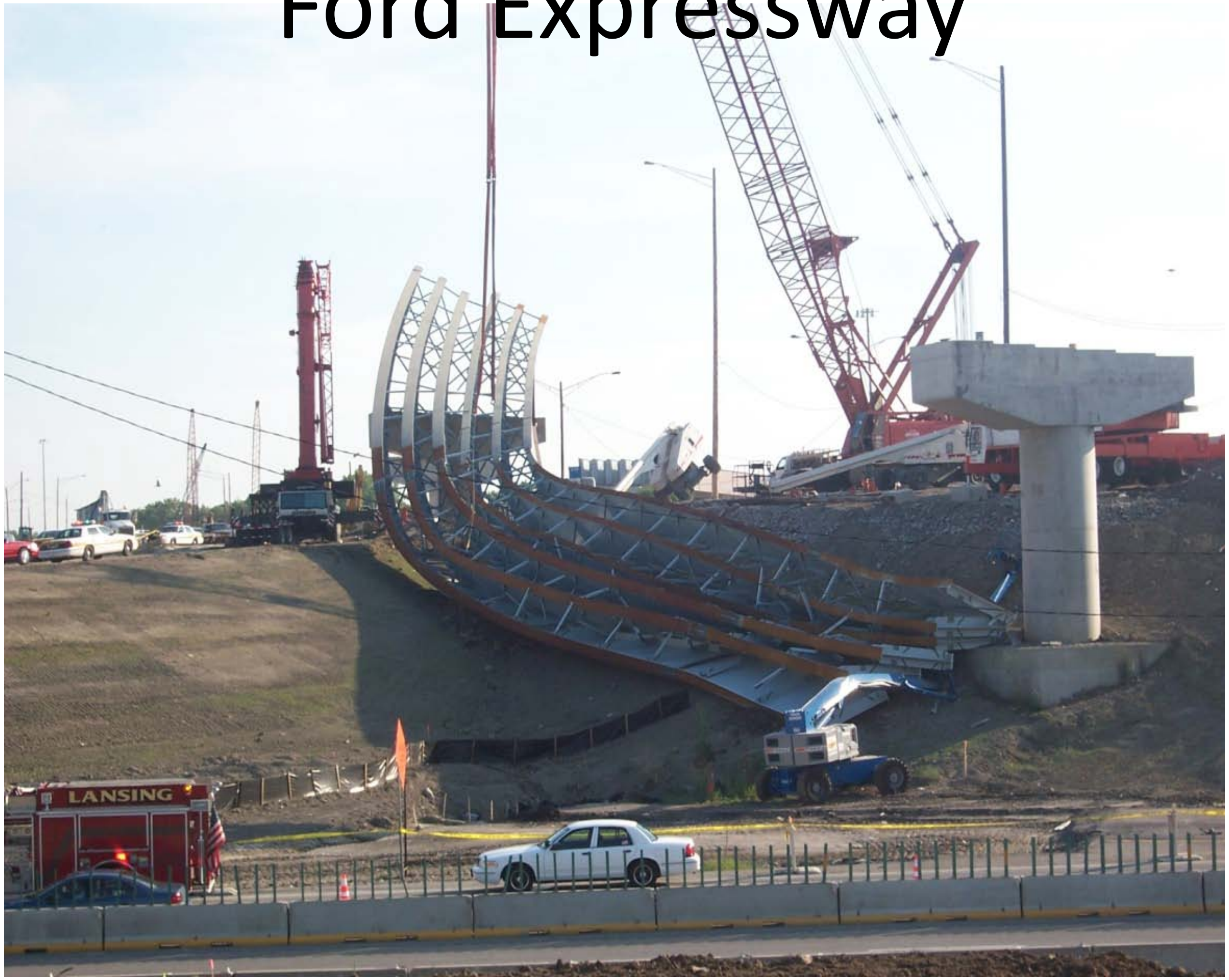
Arizona Bridge

Occurred in August 2007

Causes

- Collapse was due to lateral instability.
- Lateral instability was due to several factors:
  - Bearing eccentricity, initial sweep, thermal sweep, creep sweep, wind load.
- Providing Lateral bracings at the ends of each girder after erection, including cross bracing and diagonal bracing anchored to the caps, would have prevented lateral instabilities and the collapse.

Illinois Bridge - -80/I-294 Bishop Ford Expressway



Causes

Lateral braces were used to directly inter-connect the bridge girders, but there was no apparent horizontal cross bracing members to resist possible lateral deformations. Unfortunately, the worker in the reach-all shown in the bottom of the photograph was killed in the accident.

Maryland Requirements

- Section 420
- **Working Drawing Approval.** Submit detail, form, falsework, and centering plans and design loads for approval as specified in Section 499. Working drawings for forms shall include all members proposed for use as well as form ties and bracing. Do not submit details for form ties separately; incorporate them in the general working drawings submittal. The rate of placing concrete shall be noted on the working drawings. Approval of the working drawings does not relieve the Contractor of *responsibility* as specified in TC-4.01. The provisions of 430.03.28 also apply when working drawings are submitted for falsework and centering

- **Form Scaffolds and Platforms.** Build form scaffolds and platforms along the outside of bridge deck fascias during construction of forms for bridge decks. Design and construct them as integral parts of the form supports. Furnish separate design calculations with the working drawing submission.

Maryland Requirements

- **430.03.27 Erection Plan.** Submit an erection plan for approval outlining erection procedure of the main members. Submit the erection plan as specified in Section 499 and to the Director, Office of Bridge Development, at least 30 days prior to beginning erection. Include the numbers and types of equipment to be used including crane capacity, location of crane for lifting, falsework when required, and main member erection sequence and weight.

- **430.03.28 Falsework.** Comply with the provisions specified in TC-4.01 and Section 499. Build and maintain the falsework in accordance with the approved falsework plans. Any changes subsequent to initial approval shall be proposed through the Contractor's professional engineer and be as approved. Before permitting any loads to be placed on falsework, the Engineer shall receive written certification by the Contractor's professional engineer that the falsework system has been assembled in conformance with the approved falsework drawings. This certification shall be accompanied by a Certificate of Compliance stating that all manufactured materials and assemblies fully comply with the falsework design and plans. The Engineer may either accept the certificate or invoke any provision of GP-5.08. Perform all tests required at no additional cost to the Administration.

South Carolina

702.05 Falsework. Detailed plans shall be submitted for review to the Bridge Construction Engineer with a copy to the Engineer. The detailed plans shall be for items of work involving cofferdams, falsework over highways or railroads, falsework for caps adjacent to railroads or highways, sheeting, retaining walls and other items as designated in the plans or special provisions. The plans submitted shall be sealed by a South Carolina licensed Professional Engineer and comply with Subsection **702.10**. Review of plans shall not relieve the Contractor of responsibility for results obtained by use of these plans.

Design. Falsework/form systems shall be designed to handle all vertical and horizontal loading that may be placed upon it and shall be designed with sufficient redundancy to prevent failure of the system as a result of the failure of any individual element. Falsework shall be designed for the sum of vertical dead and live loads and an assumed horizontal load. Dead loads shall include the weight of concrete, reinforcing steel, forms and falsework. The weight of concrete shall be taken as not less than 150 pounds per cubic foot for normal concrete and not less than 120 pounds per cubic foot for lightweight concrete. Live loads shall be the actual weight of any equipment to be supported by falsework applied as concentrated loads at the points of contact and a uniform load of not less than 20 pounds per square foot applied over the area supported, plus 75 pounds per linear foot applied at the outside edge of deck overhangs.

The assumed horizontal load shall be the sum of the actual horizontal loads due to equipment, construction sequence or other causes plus not less than 50 pounds per square foot of horizontal surface area for wind, but in no case shall the assumed horizontal load be less than two percent of the total dead and live load.

Colorado Changes to Specs & Contracting Practices

- Requires an erection plan and pre-erection conference for steel and concrete girders. Requires a safety critical element conference.
- Requires the contractor to submit a bridge removal plan.
- Requires bridge contractor to retain a professional engineer that designs and approves falsework , erection plans and a demolition plan if needed.
- Added language to section 601 – "For structural steel girders, temporary struts and ties shall be provided as necessary to resist lateral loads applied to the girder flanges and to prevent appreciable relative movement between the edge of deck form and the adjacent steel girder. "

  "For structural steel girders, temporary struts and ties shall be provided as necessary to resist lateral loads applied to the girders and to prevent movement between adjacent steel girders. Where the deck overhang exceeds 1/3 of the distance between steel girders, bracing shall be provided to prevent rotation of the exterior girder due to the weight of the overhang falsework and formwork and concrete placement operations. Struts and ties shall also be provided between interior steel girders to prevent movement between girders. Falsework drawings for bracing, struts, and ties shall be submitted and conform to the requirements of subsection 601.11(a)."

Colorado Changes

The Contractor shall submit, for record purposes only, an initial detailed construction plan that addresses safe construction of each of the safety critical elements. When the specifications already require an erection plan or a bridge removal plan, it shall be included as a part of this plan. The detailed construction plan shall be submitted two weeks prior to the safety critical element conference described below. The construction plan shall be stamped “Approved for Construction” and signed by the Contractor. The construction plan will not be approved by the Engineer.

Colorado Construction Plan Requirements

- Safety Critical Element for which the plan is being prepared and submitted.
- Contractor or subcontractor responsible for the plan preparation and the work.
- Schedule, procedures, equipment, and sequence of operations, that comply with the working hour limitations
- Temporary works required: falsework, bracing, shoring, etc.
- Additional actions that will be taken to ensure that the work will be performed safely.
- Names and qualifications of workers who will be in responsible charge of the work:
  - Years of experience performing similar work
  - Training taken in performing similar work
  - Certifications earned in performing similar work
- Names and qualifications of workers operating cranes or other lifting equipment
- Years of experience performing similar work
- Training taken in performing similar work
- Certifications earned in performing similar work
- The construction plan shall address how the Contractor will handle contingencies such as:
    - Unplanned events (storms, traffic accidents, etc.)
    - Structural elements that don't fit or line up
    - Work that cannot be completed in time for the roadway to be reopened to traffic
    - Replacement of workers who don't perform the work safely
    - Equipment failure
    - Other potential difficulties inherent in the type of work being performed
- Name and qualifications of Contractor's person designated to determine and notify the Engineer in writing when it is safe to open a route to traffic after it has been closed for safety critical work.
- Erection plan or bridge removal plan when submitted as required elsewhere by the specifications. Plan requirements that overlap with above requirements may be submitted only once.

Arizona DOT Spec Changes

- 601-3.07 Section B Bridge Girder Erection

  Girders shall be placed accurately on bearings to avoid creating eccentricities capable of initiating imbalance.

  Girders with shapes that exceed a height to width ratio of two shall be temporarily braced. The girder width shall be determined from the outside dimension of the bottom flange.

  The contractor shall secure such girders in position on the structure with temporary lateral bracing to resist loads as specified in the AASHTO Guide Design Specifications for Bridge Temporary Works. Lateral bracing shall be designed to allow for girder temperature movements. The bracing shall be placed prior to the release of the erection equipment from each girder.

  Prior to erection of any girders, the contractor shall provide a lateral bracing plan, prepared and sealed by a professional engineer registered in the State of Arizona, for the Engineer's review. Such bracing plan shall be included with the working drawings specified in Subsection 105.03, and shall include supporting calculations. A girder pre-erection meeting will be scheduled following the review and prior to erection of any girders. All parties involved in the installation shall be represented, and no girders shall be placed until the plan has been approved.

  No traffic shall be allowed under each newly erected girder until the girder has been laterally braced.

  Temporary bracing shall remain in place until after permanent concrete diaphragms are installed at the bents, or the girder is integrated with a permanent feature that restricts the girder's lateral movement.

ASCE 37 –Platform Live Loads

Table 2 Classes of Working Surfaces for Combined Uniformly Distributed Loads

Operational Class	Uniform Load[a] *psf (kN/m²)*
Very light duty: sparsely populated with personnel; hand tools; *very small amounts of construction materials*	20 (0.96)
Light duty: sparsely populated with personnel; hand operated equipment; staging of materials for lightweight *construction*	25 (1.20)
Medium duty: concentrations of personnel; staging of materials *for average construction*	50 (2.40)
Heavy duty: material placement by motorized buggies; staging of materials for heavy construction	75 (3.59)

[a] Loads do not include dead load, D; construction dead load, C_D; or fixed material loads, C_{FML}.

Issues to Consider

- Wind Loads

q is calculated from formula, $q_z = 0.00256 K_z K_{zt} V^2 I (lb/sq\ ft)$

I, importance factor from ASCE 37-02, is 1.0. V is obtained from Fig 6-1 ASCE 7.

From ASCE 7 For Indiana , Vmax = 90 mph

Applying 37-02 section 6.2.1, $V = 90(0.80) = 72$ mph

K_z – Table 6-3 (ASCE 7)

Height = 30 ft. and exposure C condition. Exposure C is Open terrain which includes flat open country.

$K_{z(30)} = 0.98$

$K_{zt} = 1.0$ – No topographic factor

$q_{(30)} = 0.00256\ (0.98)\ (1.0)\ (72)^2\ (1.0) = 13$ PSF

Basic pressure equation : $p = qGC_f$

Wind Loads

Two cases: 1. Vertical forms(e.g. piers)- Horizontal 2. Horizontal Platforms - Vertical

Table 6-8
Force Coefficients for Solid Signs, C_f

At Ground Level		Above Ground Level	
ν	C_f	M/N	C_f
≤3	1.2	≤6	1.2
5	1.3	10	1.3
8	1.4	16	1.4
10	1.5	20	1.5
20	1.75	40	1.75
30	1.85	60	1.85
≥40	2.0	≥80	2.0

1. Using Table 6-8, Assume C_f = 1.5

G = 1.00

C_f = 1.5

Pressure = 13 *1 * 1.5 = **20 psf**

2. Using Table 6-6

G = 1.0

C_f = 0.75

Pressure = 13 *1*0.75 = **10 psf**

TABLE 6-6
Force Coefficients for Monoslope Roofs over Open Buildings, C_f

Roof angle θ degrees	C_f for L/B Values of: 5	3	2	1	1/2	1/3	1/5
10	0.2	0.25	0.3	0.45	0.55	0.7	0.75
15	0.35	0.45	0.5	0.7	0.85	0.9	0.85
20	0.5	0.6	0.75	0.9	1.0	0.95	0.9
25	0.7	0.8	0.95	1.15	1.1	1.05	0.95
30	0.9	1.0	1.2	1.3	1.2	1.1	1.0

Lateral Form Pressures

- ASCE 37-10 Sect 4.7.1 Proposed Form Pressures

    Cc = wh

4.7.1.1 For concrete having a slump of 7 inches (175 mm) or less, and placed with normal internal vibration to a depth of 4 feet (1.2m) or less, formwork may be designed for a lateral pressure as follows;

For Columns:

$C_C = F_C F_W$ (150 + 9000 R/T)

For Walls with a rate of placement of less than 7 feet (2.1 meters) per hour and a placement height not exceeding 14 ft (4.2 meters) per hour

$C_C = F_C F_W$ (150 + 9000 R/T) (4-3)

For Walls with a rate of placement of less than 7 feet (2.1 meters) per hour where placement height exceeds 14 feet (4.2 meters) and for all walls with a placement rate of 7 to 15 feet (2.1 to 4.5 meters) per hour

$C_C = F_C F_W$ [150 + 43,400/T + 2800 R/T]

Fc – Chemistry Factor Fw – Unit Weight Factor

Slip Form Pressures

4.7.2 Slipform Pressure

For a slipform concreting operation, the lateral pressure of fresh concrete to be used in designing the forms, bracing and wales shall be calculated as:

$C_C = c + 6000\ R/T$ (4-5)

Material Quality

- Lumber - Observe the physical condition. Look for wear , knots, splits, straightness, and moisture content. All of these will affect strength characteristics. Some reduction in design table stresses may have to be made.

- Steel – If the steel grade is unknown then assume A36. Inspect for imperfections and the allowable may have to be reduced.

Material Quality

Check Wedges

Welds

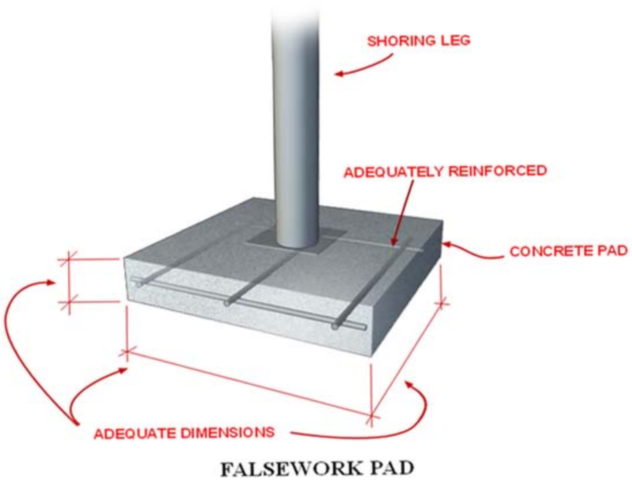
- Visually inspect welds

Foundations

- Proper support is critical.

- Review Geotechnical report for any possible recommendations for shallow foundations. If information is not sufficient then perform: In-situ testing, proof rolling for surface soils(appropriate for 2’-4’) depths., or load testing of soils.

Foundations



Lateral Loads

ASCE 37-02 has provisions for lateral loads on working platforms.

- For wheeled vehicles transporting materials, 20% for a single vehicle or 10% for two or more vehicles of the fully loaded vehicle weight. Said force shall be applied in any direction of possible travel, at the running surface.

- For equipment reactions as described in Section 4.6., the calculated or rated horizontal loads, whichever are the greater.

- 50 lbs per person (0.22kN/person), applied at the level of the platform in any direction.

- 2% of the total vertical load. This load shall be applied in any direction and shall be spatially distributed in proportion to the mass. This load need not be applied concurrently with wind or seismic load.

  This provision shall not be considered as a substitute for the analysis of environmental loads.

Thermal Distortions

ASCE 37-10 proposed language:

- “Some components can develop substantial flexural distortions and/or forces due to solar radiations on a large surface [15, 17, 18, 19, 20] during construction; this can be detrimental for a component that is designed to be shielded in the finished structure. “
- AASHTO LRFD Bridge Design Specifications Section 5.14.2.3.5

“Thermal effects that may occur during the construction of the bridge shall be considered.”

ODOT Language

ODOT 2010 Construction and Material Specifications, Section 501 (Structures) discusses designs in general. Designs must be completed according to AASHTO Standard Specifications for Highway Bridges and approved by a P.E. before being submitted to ODOT. It also states that falsework must be designed according to the AASHTO Guide Design Specifications for Bridge Temporary Works.

ITEM 508 – Falsework and Forms

Submit falsework plans for cast-in-place concrete slab superstructures according to 501.05.

501.05 Design falsework in accordance with the latest AASHTO Guide Design Specifications for Bridge Temporary Works, Section 2.

Temporary Structures are Vulnerable

Conclusions

- Are ODOT's requirements sufficient to reduce these types of risks?
- Should there be more definitive requirements?
- Temporary Lateral Bracing Requirements needed.
- A complete approach to construction loads is needed.
  - Designer Loads, construction loads types and magnitudes, specs, contractor requirements, additional costs.