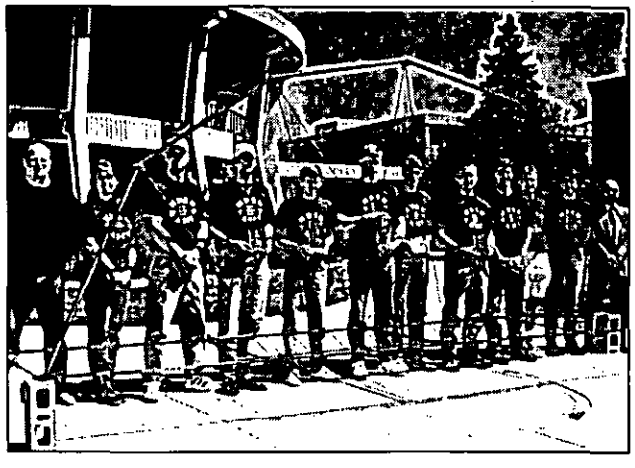
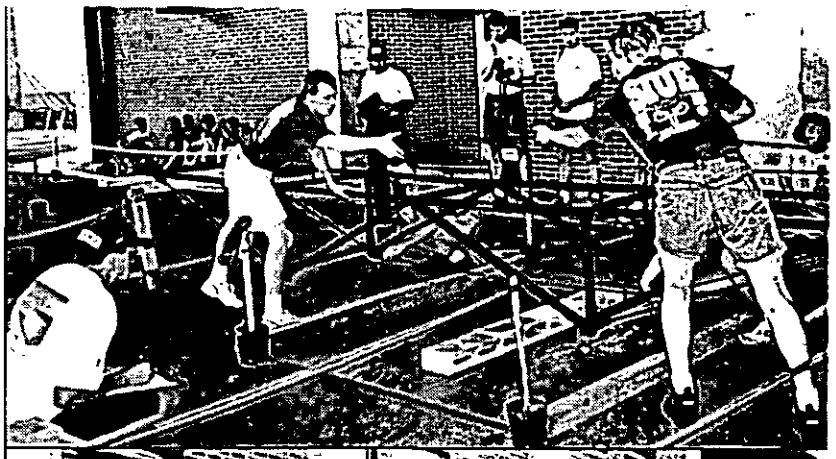
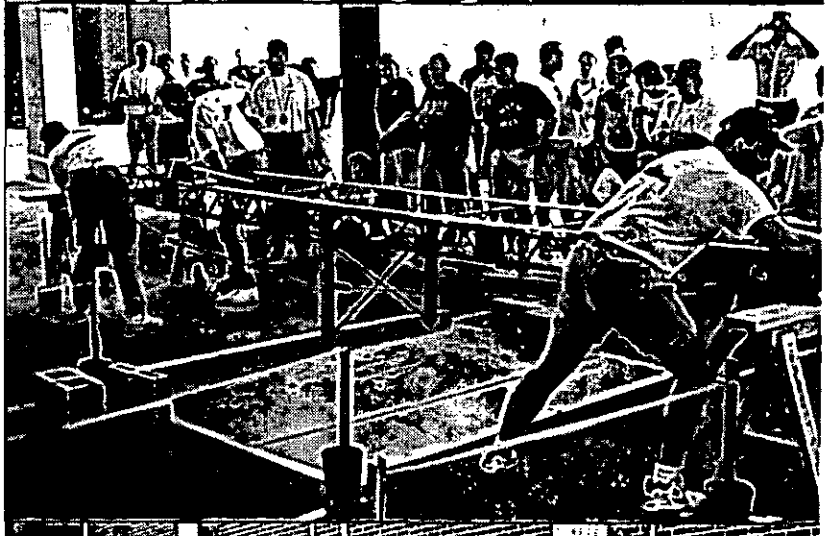
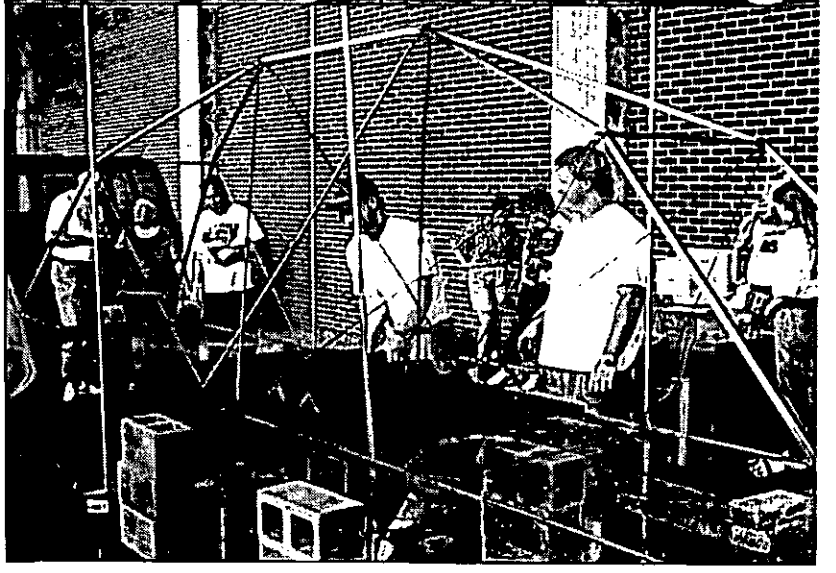
1996 STEEL BRIDGE BUILDING COMPETITION



For student chapters of the American Society of Civil Engineers







COSPONSORS

AMERICAN SOCIETY OF CIVIL ENGINEERS

American Iron and Steel Institute

THE JAMES F. LINCOLN ARC WELDING FOUNDATION

RULES

AISC STEEL BRIDGE-BUILDING COMPETITION

1996

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INTRODUCTION

The Steel Bridge-Building Competition is sponsored by the American Institute of Steel Construction and co-sponsored by the American Society of Civil Engineers, the American Iron and Steel Institute and the James F. Lincoln Arc Welding Foundation. This inter-collegiate challenge requires Civil Engineering students to design, fabricate and construct a steel bridge.

Safety is of primary importance. The AISC requests that competitors, hosts and judges take all necessary precautions to prevent injury.

The competition rules have been changed for 1996 in order to improve the contest and to assure that competitors design and build new bridges.

Ideally, students should fabricate the entire bridge themselves. However, appropriate shop facilities and supervision may not be available at every college and university. Therefore, the services of a commercial fabricator may be used provided that students observe the operations. Students are encouraged to maximize their personal involvement in fabricating their bridge.

This booklet describes the contest and states the official rules for this year. It is distributed to universities throughout the country. A companion booklet, *Guide for Hosts and Judges*, is distributed to hosts and provides directions for conducting a competition.

The rules are intended to be prescriptive but may require some interpretation. Questions regarding interpretation should be directed to the host.

EXECUTIVE SUMMARY

Civil Engineering students are challenged to an inter-collegiate competition that includes design, fabrication and construction. Participating students gain practical experience in structural design, fabrication processes, construction planning, organization and teamwork.

The Problem Statement describes challenges encountered in a representative structural engineering project. The competition is a scaled simulation of that project.

Standards for durability, constructibility, usability, strength and serviceability reflect the volumes of regulations that govern the design and construction of full-scale bridges. Criteria for excellence are represented by the award categories of stiffness, lightness, construction speed, aesthetics, efficiency and economy. As with a real construction project, safety is the primary concern.

The rules of the competition accommodate a large variety of designs and allow innovation. Designers must consider carefully the comparative advantages of various alternatives. For example, a truss bridge may be stiffer than a girder bridge but slower to construct.

The Steel Bridge-Building Competition provides design and construction planning experience, an opportunity to learn fabrication procedures, and the excitement of competing against students from other colleges and universities.

PROBLEM STATEMENT

A century-old bridge that crosses a river valley in a mountainous region must be replaced. The bridge carries heavy truck traffic to and from mines which are the basis for the economy of this rural region, as well as providing access and emergency services to residences. A quick replacement is necessary because no other river crossing of adequate capacity is available for miles.

The State Department of Transportation has requested design/build proposals for replacing the existing bridge. Any appropriate type of bridge will be considered, but the State has specified steel as the material because of its durability and fast erection. The bridge must accommodate two lanes of traffic and be able to carry specified patterns of traffic and wind loads without exceeding deflection limits. In order to expedite environmental approvals, no piers may be erected in the river, nor may temporary scaffolding or causeways be used in the river. However, temporary shoring may be erected on the banks. Construction barges and marine cranes are not feasible due to fast currents and flash floods.

The stone abutments of the existing bridge are in good condition and will serve for the new bridge, provided that no lateral thrust nor uplift is applied to the abutments. The State DOT will not permit modification of the existing abutments. The new bridge, when complete, must be supported only by the existing abutments; for example, stays and anchorages to the river banks are prohibited.

The new bridge must accommodate modular decking, which the State DOT salvaged from another bridge. Decking units may not be modified.

Access to the construction site is limited by narrow, winding roads. This imposes restrictions on the size of components, and on the movements of construction equipment. Soil conditions restrict the weight that may be lifted by cranes.

Your company's design/build proposal is among those that the State DOT has deemed responsive. The DOT has asked each competing firm to submit a 1:10 scale model to demonstrate its concept. Models will be erected under simulated field conditions and then load tested. The DOT will evaluate the models by multiple criteria including durability, constructibility, usability, stiffness, construction speed, efficiency, economy and aesthetics. The contract will be awarded to the company that submits the best model. This is an opportunity to become leaders in the bridge replacement market.

QUALIFICATION

In order to compete for awards, a bridge must qualify by satisfying the following minimum standards for durability, constructibility, usability, strength and serviceability.

Durability

The bridge must be constructed entirely of steel.

Constructibility

The bridge may be constructed only of components conforming to the restrictions on size and weight specified in "Components." The bridge must be constructible according to regulations given in "Construction" and without violating requirements listed in "Safety Regulations."

Usability

The bridge must conform to the specifications described in "Dimensions and Support."

Strength and Serviceability

The bridge must pass load tests 1 and 2 described in "Load Tests."

AWARD COMPETITION

Only qualified bridges are eligible to compete for awards. Categories of competition are stiffness, lightness, construction speed, efficiency, economy and aesthetics. In addition, overall performance is rated.

Stiffness

The bridge with the lowest incremental vertical deflection will win in the stiffness category. Incremental vertical deflection is determined from load test 3. A bridge that fails load test 3 will be eliminated from the stiffness and efficiency categories of competition.

Lightness

The bridge with the least total weight will win in the lightness category. Decking and temporary shoring are not included in total weight.

Construction Speed

The bridge with the lowest construction time will win in this category. Construction time is the product of the size of the construction team and the duration of construction. The construction team includes everyone who handles the bridge or any of its components during timed construction. A bridge that accumulates $150,000 or more in penalties will be eliminated from competition in the construction speed and economy categories (see "Accidents.")

Efficiency

The bridge with the smallest sum of normalized weight and deflection (SNWD) will win in the efficiency category. The sum of normalized weight and deflection is computed as

SNWD = Total weight (lb) + (100 x Incremental vertical deflection (in))

Economy

The bridge with the lowest cost (C) will win in the economy category. Cost is computed as

C = Total weight (lb) x 1000 ($/lb)

+ Construction time (person-min) x 5000 ($/person-minute)

+ $2000 if temporary shoring is used on one bank

+ $2000 if temporary shoring also is used on the other bank

+ Penalty for accidents (listed in "Accidents")

+ Penalty for negligent construction
(explained in "Load Tests, Repairs")

Aesthetics

Factors that may be considered include general appearance, balance and proportion of the design, elegance of connections, finish, construction organization and teamwork. Quality of fabrication should not be considered because some bridges may be fabricated professionally while others are student work.

Overall Performance

The overall performance rating of a bridge is determined by adding the rank of the bridge in the efficiency category to its rank in the economy category. The bridge with the lowest sum will win the overall competition. A bridge that was eliminated from the efficiency or economy categories is not eligible for the overall performance competition. In the case of a tie, judges will use aesthetics as the tie breaker.

COMPONENTS

A bridge may be constructed only of components made entirely of steel and conforming to the following descriptions of members, cables with fittings, assemblies, and fasteners.

A member is a rigid component that retains its shape, dimensions and rigidity during construction and in the completed bridge. A member must comply with the following limitations:

1. A member may not weigh more than 40 pounds.

2. A member may not exceed overall dimensions of 5'6" x 7.5" x 7.5."

3. A member must be rigid. That is, hinged, jointed, articulated and telescoping members are prohibited, as are members with moving parts. This prohibition includes members with parts that are intended to slide, rotate, deflect or bend relative to the member during construction, such as cams, latches, sliding pins, springs, and snap-lock devices.

4. A member may consist of several parts rigidly fastened together before timed construction begins. Those parts must remain rigidly connected throughout the construction process and in the completed bridge.

A cable with fittings is a flexible component that retains its length and flexibility during construction and in the completed bridge. A cable with fittings must comply with the following limitations:

1. A cable with fittings must be capable of being coiled to a diameter not exceeding two feet. Rigid parts must conform to the following description of fittings. Flexible parts must be coilable to the specified diameter.

2. Fittings (eyes, hooks, plates, clamps, clevises, turnbuckles and similar parts connected to cables) may not exceed 7.5" in any dimension.

3. A cable with fittings may have any number of ends.

4. A cable with fittings may not weigh more than 40 pounds.

5. A cable with fittings may consist of several parts fastened together before timed construction begins. Those parts must remain connected throughout the construction process and in the completed bridge.

An assembly is no more than 3 members and/or cables with fittings that are connected together in the staging yards during timed construction.

Fasteners are bolts and nuts, pins, plates, shims and similar parts used for connecting members, cables with fittings, and assemblies, and not exceeding 7.5" in any dimension.

CONSTRUCTION

Tools

Competitors provide their own tools. Only hand tools are permitted. Field welding and power tools are prohibited. Ropes are permitted but gin poles, jacks, winches, come-alongs, counterweights and other hoisting devices are prohibited. Stools, ladders and similar objects for elevating builders are prohibited. Hardhats are considered to be tools.

Construction Site

See the figure titled "Site Plan" for layout of river, banks, and other features that affect construction.

Temporary Shoring

Shoring is temporary support on one or both river banks, and is provided by the competitors. There are no restrictions on the materials and design for temporary shoring other than that it must provide sufficient strength and stability to support the bridge. Temporary shoring facilitates construction but there is a cost assigned to its use.

Safety Support

During construction the top of the safety support must be in place at the midspan of the bridge with its top surface no more than 8 inches below primary beams on both sides of the bridge.

Start

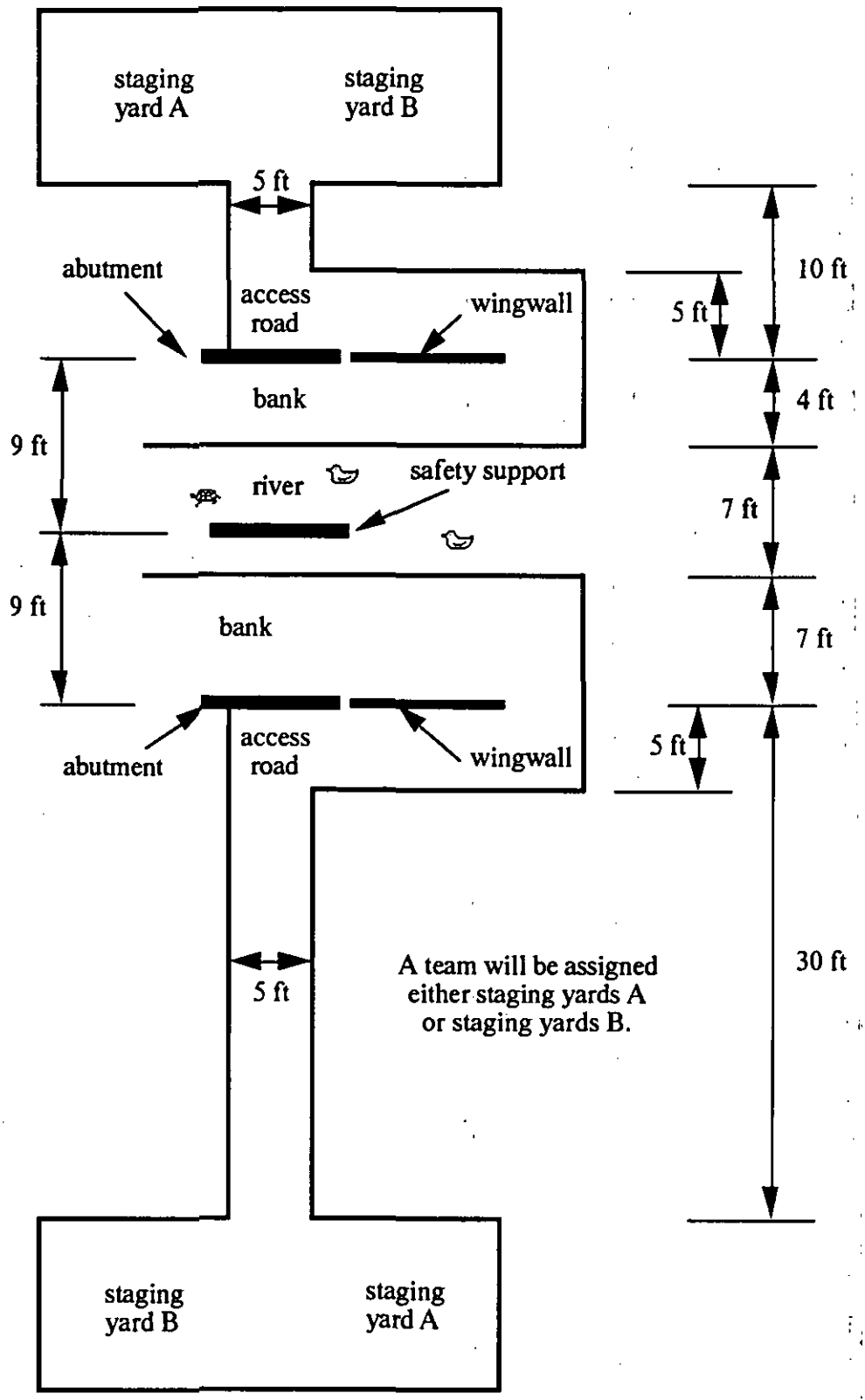
Before construction begins, all members, cables with fittings, fasteners, tools and builders are in the staging yards. Cables with fittings are coiled to a diameter not exceeding two feet. Temporary shoring, if used, is in place on one or both river banks. The safety support is in place. Timing and construction begin when the builders signify that they are ready and the judge declares the start.

Time

Time is kept from the start to finish of construction. The clock will be stopped:

1. if a builder or judge sees a condition that could cause injury,
2. when a safety regulation has been violated, or
3. if the safety support must be adjusted.

Construction ceases while the clock is stopped. The clock is restarted after the situation has been corrected.


staging
yard A
staging
yard B
5 ft
abutment
access
road
wingwall
bank
9 ft
river
safety support
9 ft
bank
abutment
access
road
wingwall
5 ft
A team will be assigned
either staging yards A
or staging yards B.
staging
yard B
staging
yard A
10 ft
5 ft
4 ft
7 ft
7 ft
5 ft
30 ft

Site Plan

Time Limit

In order to expedite the competition the host may limit the clock time for constructing a bridge to 30 minutes. A higher limit may be imposed. A bridge that exceeds the limit will be eliminated from all categories of competition. If the host opts to impose a time limit, all competitors must be notified at least a month before the competition.

Finish

Construction ends when the bridge is complete, and all tools and builders are in the staging yards, and the builders signify that they are finished. Temporary shoring may remain on the banks. Installation of decking is not included in timed construction.

SAFETY REGULATIONS

If any of the following safety regulations is violated the judge will stop the clock and explain the violation. Before restarting the clock, builders, tools and bridge components will be returned to the positions they occupied before the violation. Construction that necessitates violation of safety regulations is not permitted.

1. All builders must wear hardhats during timed construction.

2. Temporary shoring may not be placed in the river.

3. A builder may not use the bridge, an abutment or temporary shoring to support the builder's body weight. For example, standing, sitting or kneeling on those objects is prohibited. However, a builder may lean on the bridge, abutment or shoring if both feet remain on the river bank.

4. A builder may not stand, sit or kneel in the river or on the safety support, nor use the river or safety support for support in any way.

5. A builder must stay within the limits of the access roads and river banks.

6. A builder may not cross a wingwall or an abutment.

7. A builder may not cross the river by jumping, by temporary scaffolding, by crossing the bridge, or by any other means.

8. Nothing may be thrown.

9. A builder may lift or carry only one member or one cable with fittings at a time.

10. An assembly may not be lifted nor carried by one builder alone.

11. Two or more builders may lift or carry only one assembly at a time.

12. A constructed portion of the bridge (i.e. not conforming to the definitions of member, cable with fittings, or assembly) may not be lifted nor carried.

13. A constructed portion of the bridge may be slid horizontally, provided that it is supported by both abutments, or by temporary shoring on both banks, or by one abutment and one unit of temporary shoring.

14. One side or end of a constructed portion of the bridge may be moved a few inches in any direction in order to align a connection. However, the other side or end of the constructed portion must remain supported by an abutment, temporary shoring or another portion of the bridge.

15. A member, cable with fittings, assembly, fastener or tool may not be laid down except in the staging yards, on an abutment, or on the bridge.

16. A member, cable with fittings, assembly, fastener or tool may not be leaned against an abutment, temporary shoring, safety support or the bridge.

ACCIDENTS

In general, the clock is not stopped when an "accident" occurs. Builders involved in accidents may continue to build, and components involved in accidents may be recovered and used. Types of accidents and the corresponding cost penalties are:

1. A builder touches the river or the safety support. $50,000 for each occurrence.

2. A member, cable with fittings, assembly, or the bridge touches the river, a bank, an access road or the safety support. $20,000 for each occurrence.

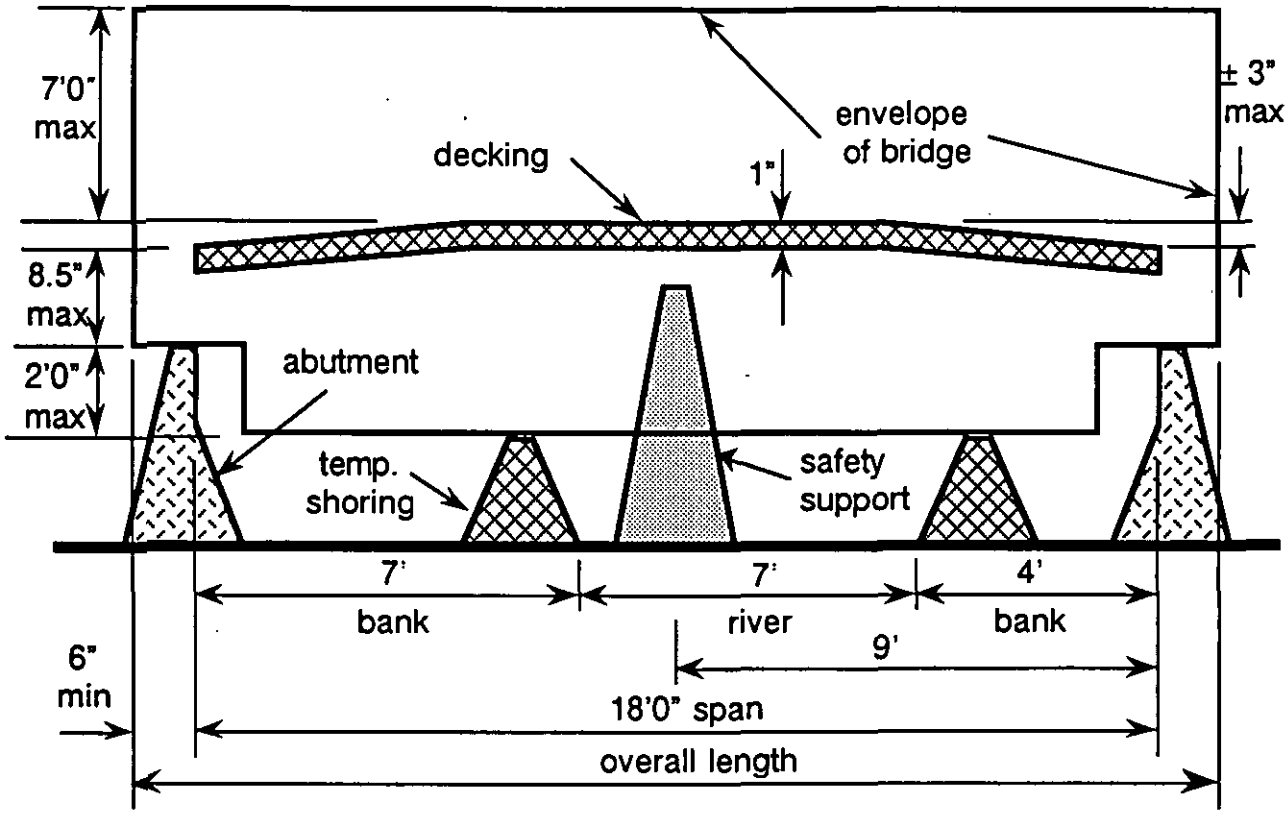
3. A tool or fastener touches the river, a bank, an access road or the safety support. $1000 for each occurrence.

DIMENSIONS AND SUPPORT

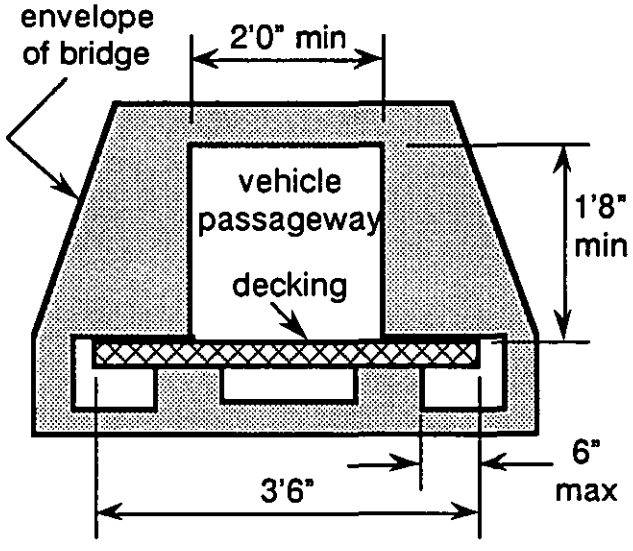
The figures titled "Side Elevation" and "Clearance and Deck Support" illustrate some of the following specifications.

1. The bridge must span the abutments, which are fixed in place so that the distance between faces is 18 feet.

2. The bridge must provide bearing area extending at least 6 inches behind the face of each abutment so that the bridge will remain supported by the abutments in the event that it is displaced 6 inches in the direction of span.



Side Elevation



Clearance and Deck Support

3. A 2'0" wide by 1'8" high rectangular vehicle passageway must be provided along the overall length of the bridge.

4. No part of the bridge may extend more than 2 feet below the top of the abutments at any point on the span.

5. No part of the bridge may extend more than 7 feet above the top of the decking at any point on the span.

6. The surface of the decking must be no more than 8.5" above the top of the abutments, measured at the abutments.

7. The absolute value of camber must not exceed 3 inches.

8. The bridge must provide support for the decking on both of the edges that run in the longitudinal direction of the bridge. The support must be continuous for the overall length of the bridge. This is easily verified by sliding a piece of decking along the full overall length of the bridge.

9. Decking must be supported without gaps, overlaps or abrupt elevation differences between decking units. However, small elevation differences, such as those caused by decking resting on bolt heads, are acceptable.

10. The edges of the decking that run in the longitudinal direction of the bridge may be cantilevered over their supports no more than 6 inches.

11. The decking may not be attached nor anchored to the bridge.

12. The bridge may not be attached nor anchored to the abutments, and it may bear only on the top surface of the abutments.

13. The bridge may not be anchored, tied nor braced to the ground.

LOAD TESTS

Safety Precautions

A bridge could collapse or sway suddenly during load tests. Therefore:

Minimize the number of people near the bridge while it is being tested.

If abutments are adjustable, set them so that the bottom of the bridge is 5 to 8 inches above ground.

During testing, safety support must be in place 5 to 8 inches below the bottom of the decking.

Do not exceed 400 psf uniform load or 500 pounds concentrated load on the decking. Do not load on a cantilevered portion of the decking.

When any portion of the vertical load is on the bridge, no one is permitted to crawl, reach or step under the bridge. If such an action is necessary, the load must first be removed.

Repairs

A bridge will not be tested in a condition that compromises its strength or stability. Therefore, immediately prior to load testing, repairs may be made with the permission and supervision of a judge, according to the following provisions:

1. Damage occurring after construction will be repaired without penalty.

2. Minor construction errors will be repaired without penalty. For example, a turnbuckle may be re-adjusted to correct a slight misalignment of a primary component with no penalty.

3. Errors due to negligent construction will be repaired but a cost penalty will be assessed in an amount, to be determined by the judge, that will exceed the incremental cost of careful initial construction. For example, a team that forgets to install bracing or makes no attempt to adjust turnbuckles during timed construction will be penalized.

4. Deliberate exploitation of these repair provisions constitutes negligent construction and will be penalized heavily.

General Procedures and Definitions

Load tests are conducted without temporary shoring. Load test 1 is conducted without decking; load tests 2 and 3 are conducted with three decking units installed to accommodate the load.

The judge selects a side of the bridge and marks a target at midspan on that side, close to the level of the decking. All lateral deflection measurements are made to that target.

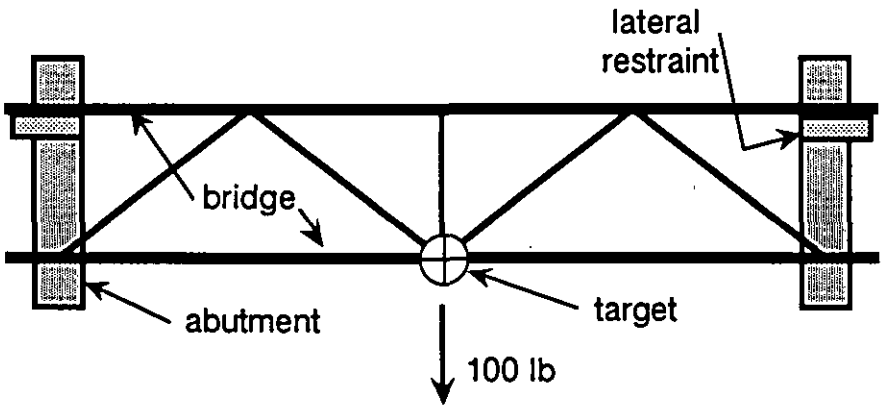
The judge selects a side of the bridge and marks targets at the third points of the span (i.e. 6 and 12 feet from the faces of the abutments). The targets should be close to the level of the decking. Vertical deflection measurements are made to both targets; vertical deflection is the larger absolute value of the two measurements.

Total lateral deflection is the absolute value of the horizontal distance of the target from its position at the beginning of load test 2. Incremental vertical deflection is the larger absolute value of the vertical distances of the targets from their positions at the beginning of load test 3.

Load tests are conducted in numerical order.

Load Test 1 - Qualifying, Lateral

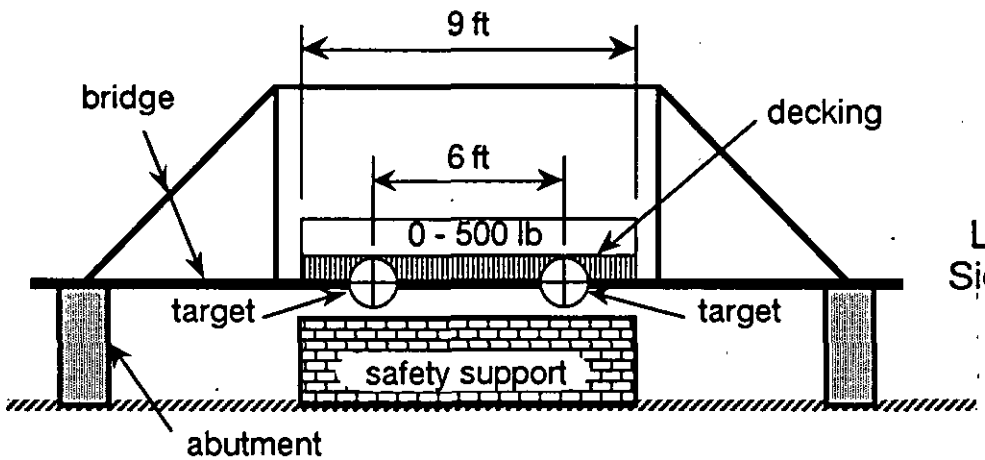
Load test 1 is conducted with lateral restraint installed on the abutments to prevent the ends of the bridge from sliding. As close as practical to midspan and to the level of the deck apply a 100 pound force in the lateral direction. To pass load test 1, the lateral deflection of the bridge must not exceed 1.0". If the bridge does not pass load test 1, do not conduct any other load test. Remove the lateral load; it is not part of the remaining load tests.



Load Test 1
Plan

Load Test 2 - Qualifying, Vertical

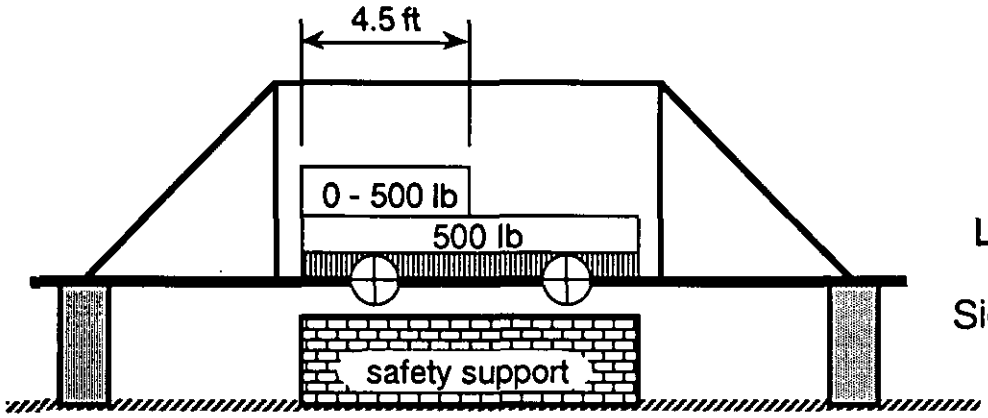
Uniformly distribute load over an area symmetric about the middle of the deck and extending 9 feet in the span direction, as shown in the figure. Terminate load test 2 when lateral deflection exceeds 1.0" or vertical deflection exceeds 2.0" or 500 pounds of load have been placed. A bridge passes load test 2 if 500 pounds of load was placed without a deflection limit being exceeded. Record the vertical deflection. If the bridge does not pass load test 2, do not conduct any other load test.



Load Test 2
Side Elevation

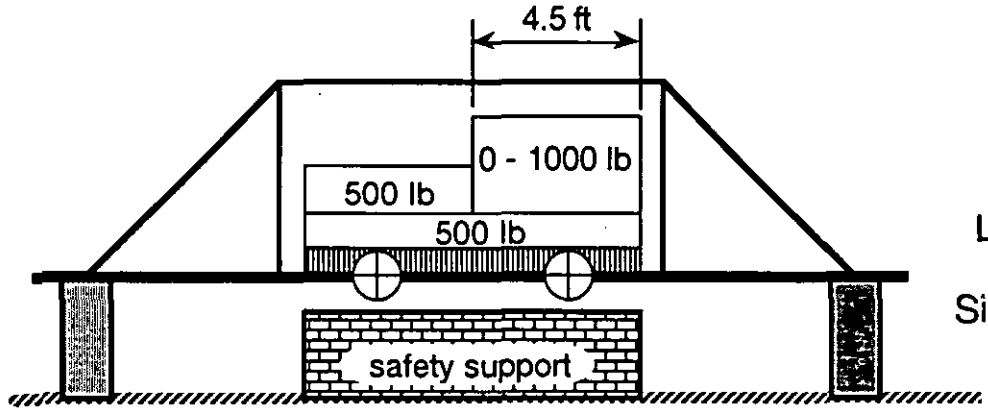
Load Test 3 - Competition, Vertical

Step 1. With the 500 pound load from test 2 remaining in place, uniformly distribute additional load over an area symmetric to the midline of the deck and extending 4.5 feet from midspan toward an end designated by the judge. That is, the load is longitudinally eccentric, as shown in the figure. Terminate step 1 when total lateral deflection exceeds 2.0" or incremental vertical deflection exceeds 2.0" or total load is 1000 pounds. Terminate load test 3 if either deflection limit is exceeded.



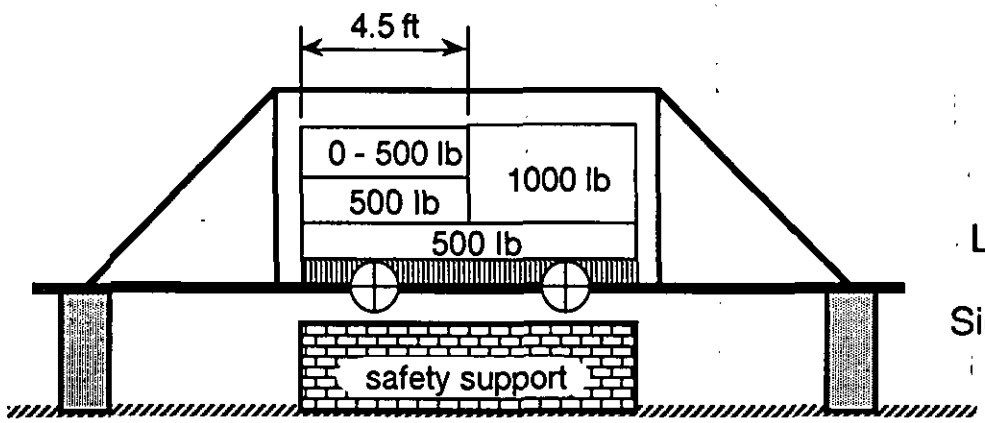
Load Test 3
Step 1
Side Elevation

Step 2. With previous loads remaining in place, uniformly distribute additional load over an area symmetric to the midline of the deck and extending 4.5 feet from midspan toward the end opposite to the one designated by the judge in step 1. That is, the eccentricity is reversed, as shown in the figure. Terminate step 2 when total lateral deflection exceeds 2.0" or incremental vertical deflection exceeds 2.0" or total load is 2000 pounds. Terminate load test 3 if either deflection limit is exceeded.



Load Test 3
Step 2
Side Elevation

Step 3. With previous loads remaining in place, uniformly distribute additional load over an area symmetric to the midline of the deck and extending 4.5 feet from midspan toward the end designated by the judge in step 1. That is, the load restores symmetry, as shown in the figure. Terminate testing when total lateral deflection exceeds 2.0" or incremental vertical deflection exceeds 2.0" or total load is 2500 pounds. If the total load of 2500 pounds was placed without a deflection limit being exceeded, then the bridge passes load test 3. Record the incremental vertical deflection (that is, the larger absolute value of the vertical distances of the targets from their positions at the start of test 3).



Load Test 3
Step 3
Side Elevation

EQUIPMENT PROVIDED BY HOST

The following equipment will be provided at the contest site by the host. Competitors should acquire similar equipment for use in practice and testing before the competition.

Lateral Load Device

Capable of applying 100 pound force in the horizontal direction.

Measuring Scales and/or Instruments

Load

2500 pounds total. The load should be supplied in uniform pieces of size and weight that may be handled safely. When in place, the load should not provide significant stiffness in the longitudinal direction of the bridge. Sections of steel angle of uniform size and length are recommended for load. Sacks of material, containers of liquid, concrete blocks or jacking systems could be used.

Decking

The decking is steel bar grating identified as W-19-4 (1 x 1/8). The dimensions of a piece of grating are 3'6" x 2'11-3/4" x 1". Grating has significant bending strength only in the direction of the main bars, which are 3'6" long. The grating will be installed with the main bars perpendicular to the length of the bridge, creating a roadway that is 3'6" wide. Therefore, support for the grating is needed for the edges that are parallel to the length of the bridge, but not for the edges of the grating that are perpendicular to the length.

Abutments

Construction. The top surface of each abutment should be at least 5 feet long, 3 inches wide, level, smooth, and approximately 3 feet above the ground.

Load Testing. A different set of abutments may be used during load testing. The top surface of each abutment should be at least 5 feet long, 3 inches wide, level and smooth. Height may be adjustable so that the bridge may be positioned close to the ground. Temporary lateral restraints are needed during load test 1.

Safety Support

Construction. The safety support is intended to limit the consequences of a bridge collapsing or sliding off the abutments during construction. The safety support should be placed at the middle of the span and adjusted to the proper height before the start of timed construction. At all times during construction the top of the safety support should be no more than 8 inches below primary beams on both sides of the bridge. If the safety support must be adjusted when the bridge is partially constructed, the clock will be stopped while the safety support is re-positioned.

Load Testing. A different safety support should be used during load testing. This safety support is intended to limit the consequences of a bridge collapsing during load tests. The safety support should be at least 6 feet long and adjustable in width, and should be centered under the bridge. The safety support must be placed before the beginning of load testing, with the top 5 to 8 inches below the bottom of the decking.

JUDGING

The host will recruit judges. Judges are empowered to halt any activity that they deem to be hazardous. Judges have full authority over conduct of the competition and interpretation of ambiguities in the rules. Decisions, scoring, rating and disqualification are the sole responsibility of the judges and will be final. The host will assure that the judges are fully informed of the rules and procedures, and fully equipped for their tasks. The host and judges will follow directions in the *Guide for Hosts and Judges* provided by AISC.

TIPS FOR COMPETITORS

1. Strive for challenging but realistic goals for design and construction. The following statistics from the 1995 National Steel Bridge-Building Competition suggest the levels of performance that are possible. However, when reviewing these statistics keep in mind that the rules and scoring for 1996 differ from those for 1995.

	Winning bridge in category	Winning bridge, overall
Weight (lb)	70	84
Construction time (person-minutes)	6.52	8.8
Incremental vertical deflection (inches)	0.111	0.14

2. Start work on the design early, leaving adequate time to procure materials, fabricate the bridge, load test it and practice construction.

3. Design a bridge that may be fabricated, erected and load tested safely.

4. Design a bridge that may be fabricated with available materials, tools and facilities.

5. Structural analysis may fail to disclose instability, such as buckling of slender compression members, sway, and torsion of under-deck trusses of triangular cross-section.

6. Allow tolerances for the decking to be slightly larger or smaller than specified. Provide adequate clearances so that the decking may be installed anywhere on the overall length.

7. Allow tolerances for spacing and levelness of abutments.

8. When fabricating your bridge, use safe tools, operate them carefully and with adequate supervision.

9. Make sure that abutments, safety supports and temporary shoring are strong enough (with a generous factor of safety) and will not tip during construction practice or if the bridge collapses during load testing.

10. When practicing construction, use a safety support and wear hardhats for safety and to accustom yourself to contest conditions.

11. Follow all safety regulations and guidelines during construction practice.

12. When load testing your bridge before the competition keep it as low to the ground as possible and place safety support a few inches below the decking under at least 6 feet of the span. This will reduce risk of injury and limit damage to the bridge if it collapses. Keep hands and feet out from under the bridge.

13. Don't stand, sit or lie on your bridge.

14. To expedite the competition have a preset plan for unloading and staging components of your bridge. Before the competition adjust your temporary shoring to conform to the height of the host's abutments. Know in advance the required elevation of the safety support.

SCORE SHEET

Penalties

Builder touches river or safety support ($50,000 each) $_____

Part touches river, bank, road or safety support ($20,000 each) $_____

Tool or fastener touches river, bank, road or safety support ($1000 each) $_____

Negligent construction (see "Load Tests, Repairs") $_____

TOTAL PENALTIES $_____

Construction Time

_____ builders x _____ min = _____ person-min

Total Weight

_____ pounds

Aesthetics

Items that may be considered:

General appearance	Balance and proportion
Finish	Elegance of connections
Construction organization	Teamwork

AESTHETICS SCORE _____

Deflection (incremental vertical, test 3) _____ inches

Efficiency

Total weight (lb) _____ = _____

Incremental vert. deflect. (in) _____ x 100 = +_____

SNWD (add) _____

Cost

Temporary Shoring ($2000 if used on one bank
or $4000 if used on both banks) $_____

Const. Time _____ x $5000 = +$_____

Weight _____ x $1000 = +$_____

Total Penalties +$_____

TOTAL COST (add) $_____

Rank

Construction Speed _____ Efficiency _____

Lightness _____ Economy _____

Stiffness _____ Aesthetics _____

Overall Performance (Efficiency + Economy) = _____

Use aesthetics as tie breaker