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Section 8

Inspection and Evaluation of Common Steel Superstructures

Topic 8.9 Steel Rigid Frames

8.9.1 Introduction

A frame is a multi-sided configuration in which the sides are rigidly connected in such a fashion that applied loads are distributed to each side (see Figure 8.9.1). Steel rigid frames are popular today in building construction because of their space-saving characteristics. The same principles that permit the omission of intermediate column supports in buildings are applied to bridge frames. In a steel rigid frame bridge structure, the frame sides or "legs" replace intermediate supports. Because the legs contribute to the structures overall capacity, increased span lengths and material savings can be realized.

Figure 8.9.1 Typical Rigid K-frame Constructed of Two Frames

8.9.2 Design Characteristics

General

Frames are not referred to as having a single, simple, multiple, or continuous spans. Also, steel rigid frame structures are used only in straight horizontal applications.

Steel rigid frame bridges typically consist of welded plate girder construction with bolted field splices in low stress areas and welded stiffeners in high stress areas. The frames are spaced from about 2 to 6 m (7 to 20 feet) on centers, depending on loads, span lengths, and type of floor system. Steel rigid frames can be economical for spans from 15 m (50 feet) to over 61 m (200 feet). Standard abutments and expansion bearings support the ends of the frame girders.

The superstructure of a rigid frame bridge can be constructed of two frames similar to a two-girder bridge (see Figure 8.9.1) or of multiple frames in the same manner as a multi-girder bridge (see Figure 8.9.2). These frames can be thought of as fabricated girders with legs.

Figure 8.9.2 Typical Rigid Frame Constructed of Multiple Frames

K – Frames

Most steel rigid frame bridges are multi-span structures and are commonly referred to as "K-frame" or "grasshopper leg" bridges (see Figure 8.9.3). The sloping legs give the rigid frame a "K" shape, when looked at by rotating the frame counterclockwise 90°. K-frames are not economical for very short or very long span bridges. Because of their aesthetically pleasing appearance, sometimes an effort is made to use steel rigid frames whenever possible.

Figure 8.9.3 Typical K-frame

It is possible to think that the legs of the K-frame look very much like piers and consider them part of the substructure. This is not the case because there is no bearing between the legs and the girder portion of the frame (see Figure 8.9.3).

Since there are no bearings between the legs and girder portion of the frame, bending forces are transferred between the girder portion and the legs (see Figure 8.9.4).

Figure 8.9.4 Connection Between Legs and Girder Portion

Delta Frames

In some designs, a triangular frame configuration can be used. For very long spans, two K-frames can be connected together end-to-end (see Figure 8.9.5). Instead of one of the end spans bearing on an abutment, it is connected to the end span of another K-frame. The bottoms of the legs are also connected together and share the same bearing. This type of configuration is known as a delta frame. The leg connections form an inverted triangle with the girder portion of the frame. The Greek letter Delta (∇) is the symbol used for this triangle.

Figure 8.9.5 Delta Frame

Regardless of the frame configuration, the entire portion of the bridge, (legs and girders) constitutes the frame, and is considered the superstructure. The legs of rigid frames are supported by relatively small concrete footings and bearings which are essentially hinges (see Figure 8.9.6).

Figure 8.9.6 Bearing

Stiffeners

Steel rigid frames may have up to three different types of stiffeners (see Figure 8.9.7).

Transverse Stiffeners

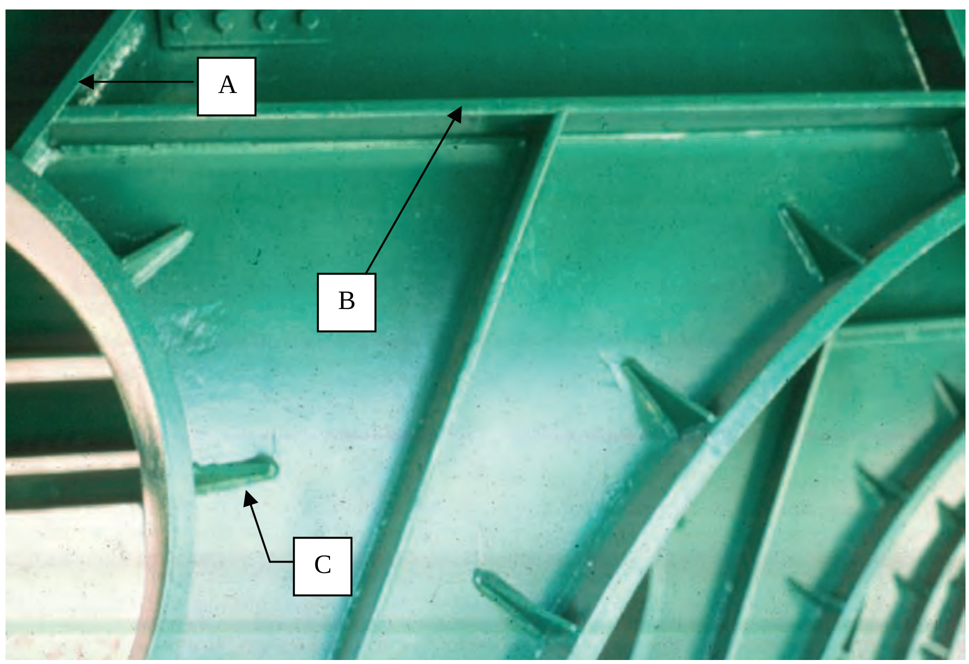
Transverse stiffeners are placed approximately perpendicular to the flanges and welded to the web and flanges of the frame at spacings required by design. Transverse stiffeners are used to prevent buckling in high shear regions.

Longitudinal Stiffeners

Longitudinal stiffeners are placed parallel to the flanges and welded to the web of the frame. They may extend the entire length of the frame girder or just in areas of high moment. Longitudinal stiffeners resist web buckling in the compression zone and therefore are closer to the top flange in areas of higher positive moment and closer to the bottom flange in areas of higher negative moment.

Radial Stiffeners

Radial stiffeners are placed perpendicular along the frame knee bottom flange radius. The radial stiffeners are welded to the flange and web at spacings required by design. This type of stiffener is used to resist shear and moment forces in the knee.



Stiffeners
A – Transverse
B – Longitudinal
C – Radial

Figure 8.9.7 Transverse, Longitudinal, and Radial Stiffeners on a Frame Knee

Floor System Arrangement

A rigid frame will have one of three floor systems:

Multiple Frame System

For a multiple frame system, the deck is supported only by the frames (see Figure 8.9.2).

Frame-Floorbeam System

Floorbeams are connected to the girder portion of the two frames. The floorbeams are much smaller than the girder portion of the frame and are perpendicular to the flow of traffic. The deck is supported by the floorbeams, which in turn transmit the loads to the frames. The floorbeams can be either rolled beams, fabricated girders, or fabricated cross frames.

Frame-Floorbeam-Stringer System

Longitudinal stringers, parallel to the frames, are connected to the floorbeams (see Figure 8.9.8). Floorbeams are connected to the girder portion of the two frames. The stringers are typically rolled sections and are connected to the web of the floorbeams.

Figure 8.9.8 Two Frame Bridge with Floorbeam-Stringer Floor System

Primary and Secondary Members

For steel rigid frame bridges, the primary members are the frames as a whole, including floorbeams and stringers (if present) (see Figure 8.9.8). However, for ease of discussion, the frame is commonly broken down into the following five elements:

- Frame girder - the horizontal sections
- Frame leg - the inclined sections
- Frame knee - the intersection between the frame girder and frame leg
- Floorbeams (if present)
- Stringers (if present)

The primary members consist of the frames and floor system. The frame girder, frame knee and frame leg make up the frame. If present, the floor system consists of floorbeams and stringers (see Figure 8.9.9).

Secondary members consist of lateral bracing, sway bracing and diaphragms.

In a two frame system, lateral bracing members are placed diagonally between the frames. This bracing restricts any differential and longitudinal movements between the frames. This bracing is in the plane of the bottom flange of the girder portion of the frame or between the legs of the frame (see Figure 8.9.10).

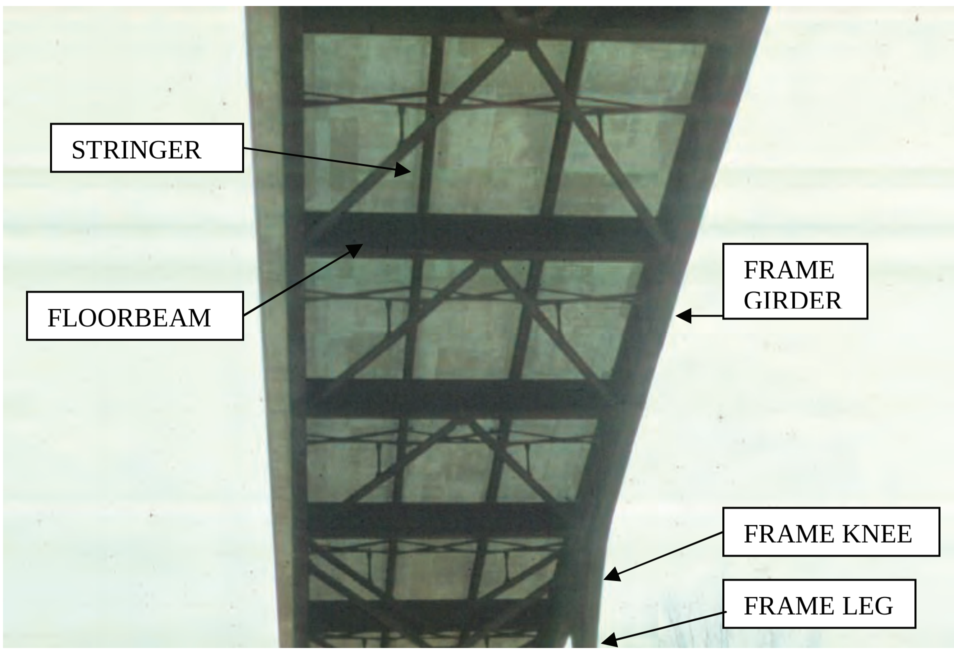


Figure 8.9.9 Frame Members, Floorbeams, and Stringers

In a two frame system, sway bracing is placed between the leg portions of the frame (see Figure 8.9.10). In a multiple frame system diaphragms are placed perpendicular between the frames. The sway bracing and diaphragms minimize any transverse movements of the frames (see Figure 8.9.11).

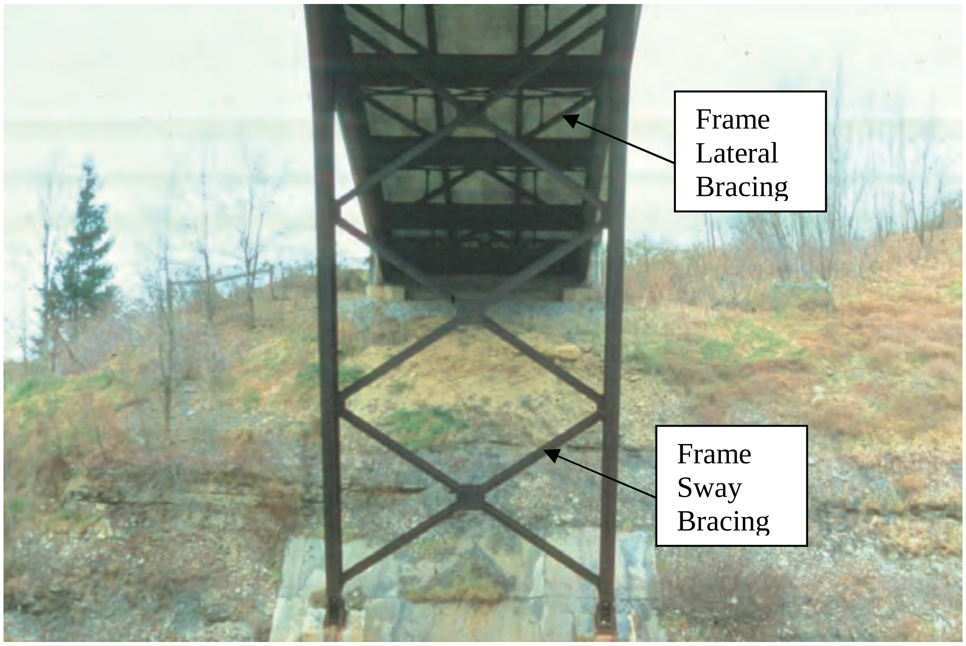


Figure 8.9.10 Lateral Bracing for the Frame Legs

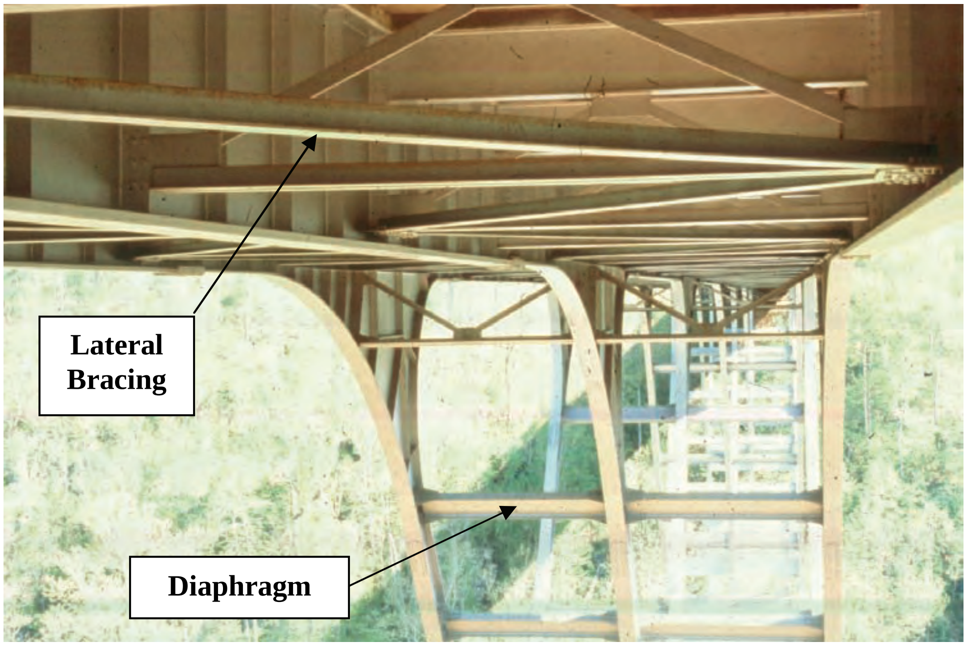


Figure 8.9.11 Lateral Bracing and Diaphragms

Stress Zones

Each element of the frame resists various levels of stress due to moment and shear. Tension zones are similar to those for concrete rigid frames (see Figure 8.9.12).

Stress zones for the floor systems are similar to the two-girder floor systems discussed in Topic 8.3.

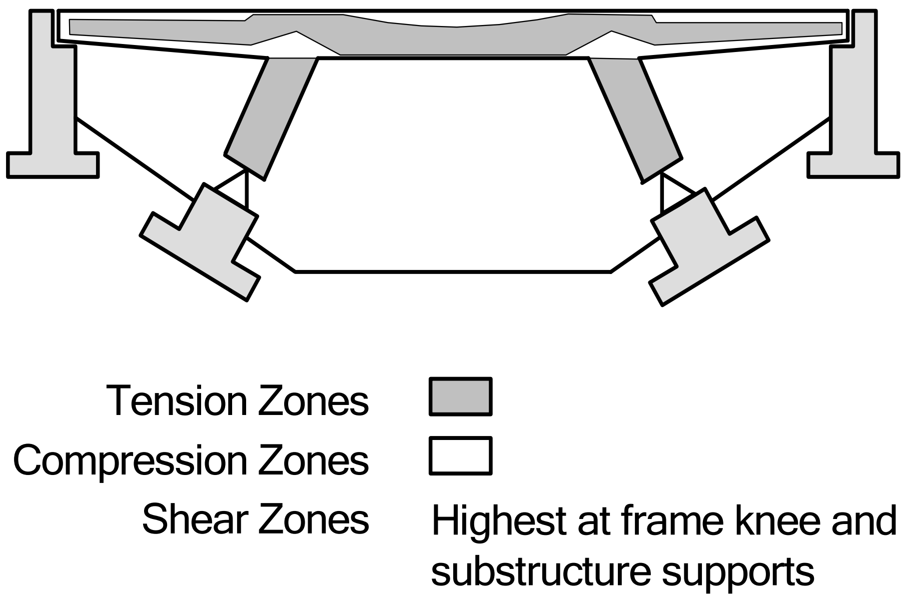


Figure 8.9.12 Stress Zones in a Frame

Fatigue Prone Details and Failure

Some common areas for fatigue prone details are:

- Fabrication welds
- Welded cover plates
- Web stiffener welds
- Welded flange splices
- Intersecting welds
- Attachment welds located in the tension zone
- Web gaps
- Mechanical splices

Inspection of these areas is discussed in Topic 8.9.4.

Fracture Critical Areas

A rigid frame consisting of two frames has no load path redundancy. This means that a two frame steel rigid frame is a fracture critical bridge type (see Figure 8.9.13).

Figure 8.9.13 Dual Frame Rigid Frame – A Fracture Critical Structure

A rigid frame bridge consisting of three or more frames has load path redundancy and is not fracture critical (see Figure 8.9.14).

Figure 8.9.14 Multiple Frame Rigid Frame – Not a Fracture Critical Structure

8.9.3 Overview of Common Defects

Common defects that occur on steel rigid frame bridges include:

- Paint failures
- Corrosion
- Fatigue cracking
- Collision damage
- Overloads
- Heat damage

See to Topic 2.3 for a detailed presentation of the properties of steel, types and causes of steel deterioration, and the examination of steel. Refer to Topic 8.1 for Fatigue and Fracture in Steel Bridges.

8.9.4 Inspection Procedures and Locations

Inspection procedures to determine other causes of steel deterioration are discussed in detail in Topic 2.3.8.

Procedures

Visual

The inspection of steel bridge members for defects is primarily a visual activity.

Most defects in steel bridges are first detected by visual inspection. In order for this to occur, a hands-on inspection, or inspection where the inspector is close enough to touch the area being inspected, is required. More exact visual observations can also be employed using a magnifying unit after cleaning the paint from the suspect area.

Physical

Removal of paint can be done using a wire brush, grinding, or sand blasting, depending on the size of the suspected defect. The use of degreasing spray before and after removal of the paint may help in revealing the defect.

When section loss occurs, use a wire brush, grinder or hammer to remove loose or flaked steel. After the flaked steel is removed, measure the remaining section and compare it to a similar section with no section loss.

The usual and most reliable sign of fatigue cracks is the oxide or rust stains that develop after the paint film has cracked. Experience has shown that cracks have generally propagated to a depth between one-fourth and one-half the plate thickness before the paint film is broken, permitting the oxide to form. This occurs because the paint is more flexible than the underlying steel.

Smaller cracks are not likely to be detected visually unless the paint, mill scale, and dirt are removed by carefully cleaning the suspect area. If the confirmation of a possible crack is to be conducted by another person, it is advisable not to disturb the suspected crack area so that re-examination of the actual conditions can be made.

Once the presence of a crack has been verified, the inspector should examine all other similar locations and details.

Advanced Inspection Techniques

Several advanced techniques are available for steel inspection.

Nondestructive methods, described in Topic 13.3.2, include:

- Acoustic emissions testing
- Computer programs
- Computer tomography
- Corrosion sensors
- Smart paint 1
- Smart paint 2
- Dye penetrant
- Magnetic particle
- Radiographic testing
- Robotic inspection
- Ultrasonic testing
- Eddy current

Other methods, described in Topic 13.3.3, include:

- Brinell hardness test
- Charpy impact test
- Chemical analysis
- Tensile strength test

Locations

Bearing Areas

Examine the floor system, frame knee area and the web areas over the supports for cracks, section loss or buckling. If bearing stiffeners, jacking stiffeners and diaphragms are present at the supports inspect them for cracks, section loss and buckling also.

Examine the bearings at each support for corrosion. Check the alignment of each bearing and note any movement. Report any build up of debris surrounding the bearings that may limit the bearing from functioning properly. Check for any bearings that are frozen due to heavy corrosion (see figure 8.9.15). See Topic 9.1 for a detailed presentation on the inspection of bearings.

Figure 8.9.15 Bearing Area of a Two Frame Bridge

Shear Zones

Examine the web area of the girder portion near the bearings and knee areas for section loss due to corrosion. Check the web area of the girder portion near the bearings and knee areas for buckling. Inspect floorbeams and stringers (if present) near their respective bearing areas for corrosion or buckling. Check the bottom of the frame legs for corrosion or buckling.

Flexure Zones

Check the tension and compression flanges for corrosion, section loss, cracks or buckling (see Figure 8.9.16). Special attention should be given to the flanges at the connection between the legs and girder portion of the beam. Bending moment is at its highest in this area.

Figure 8.9.16 Flexural Zones

Secondary Members

Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration. Investigate the areas beneath drainpipes and deck joints for corrosion from exposure to roadway drainage. Examine the connection areas of the lateral bracing or diaphragms for cracked welds, fatigue cracks, and loose fasteners. Check for distortion in the secondary members. Distorted secondary members may be an indication the primary members are overstressed of the substructure may be experiencing differential settlement.

Areas that Trap Water and Debris

The areas that trap water and debris result in active corrosion cells and can cause in notches susceptible to fatigue or perforation and loss of section. On rigid frame bridges check horizontal surfaces that include top of bottom flange, lateral bracing gusset plates and pockets created by floor system connections.

Areas Exposed to Traffic

Check underneath the bridge for collision damage to the frame sections and bracing if the bridge crosses over a highway, railway, or navigable channel. Document any cracks, section loss, scrapes or distortion found.

Fatigue Prone Details

Examine any attachment welds located in the tension areas of the frame or floor system. Check web stiffener welds. Pay close attention to the knee area. Vertical, longitudinal, and radial stiffeners may all be present, and there may be a possibility of intersecting welds (see Figure 8.9.17). Inspect welded flange splices, particularly where changes in thickness and/or width occur (see Figure 8.9.18).

Figure 8.9.17 Knee Area: Fatigue Prone Details

Figure 8.9.18 Welded Flange Splice

8.9.5 Evaluation

State and federal rating guideline systems have been developed to aid in the inspection of steel superstructures. The two major rating guideline systems currently in use are the FHWA's *Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation's Bridges* used for the National Bridge Inventory (NBI) component rating method and the AASHTO element level condition state assessment method.

NBI Rating Guidelines

Using the NBI rating guidelines, a 1-digit code on the Federal Structure Inventory and Appraisal (SI&A) sheet indicates the condition of the superstructure. Rating codes range from 9 to 0 where 9 is the best rating possible. See Topic 4.2 (Item 59) for additional details about NBIS Rating Guidelines.

The previous inspection data should be considered along with current inspection findings to determine the correct rating.

Element Level Condition State Assessment

The element level method does not have specific CoRe elements for steel rigid frames. Due to this fact, individual states may choose to create their own non-CoRe elements or use the AASHTO CoRe elements that "best describe" the rigid frame. In an element level condition state assessment of a steel rigid frame bridge, the AASHTO CoRe elements that relate closest to a rigid frame include:

Element No.	Description
106	Unpainted Steel Open Girder/Beam
107	Painted Steel Open Girder/Beam
112	Unpainted Steel Stringer (Stringer Floorbeam System)
113	Painted Steel Stringer (Stringer Floorbeam System)
151	Unpainted Steel Floorbeam
152	Painted Steel Floorbeam
201	Unpainted Steel Column or Pile Extension
202	Painted Steel Column or Pile Extension

The unit quantity for the rigid frame is meters or feet, and the total length must be distributed among the four available condition states for unpainted and five available condition states for painted structures depending on the extent and severity of deterioration. The unit quantity for columns is each and the total quantity must be placed in one of the four available condition states for unpainted and five available condition states for painted. In both cases, Condition state 1 is the best possible rating. See the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* for condition state descriptions.

For states that create their own non-CoRe elements, the bridge inspector must use that particular state's Bridge Inspection Manual to determine the appropriate non-CoRe element(s) as well as the correct condition state(s).

A Smart Flag is used when a specific condition exists, which is not described in the CoRe element condition state. The severity of the damage is captured by coding the appropriate Smart Flag condition state. The Smart Flag quantities are measured as each, with only one each of any given Smart Flag per bridge.

For damage to fatigue, the "Steel Fatigue" Smart Flag, Element No. 356, can be used and one of the three condition states assigned. For rusting between riveted members, the "Pack Rust" Smart Flag, Element No. 357, can be used and one of the four condition states assigned. For damage due to traffic impact, the "Traffic Impact" Smart Flag, Element No. 362, can be used and one of the three condition states assigned. For steel rigid frames with section loss due to corrosion, the "Section Loss" Smart Flag, Element No. 363, can be used and one of the four condition states assigned.