

Rating Deteriorated Members: Section Loss and Condition Factors

Most bridges that need a careful load rating are not new. They have corroded flanges, perforated webs, spalled and delaminated concrete, exposed and section-reduced reinforcing, and bearings that no longer work as designed. This course covers how a load rating engineer turns inspection findings into the section properties used in an LRFR rating, how the condition factor (MBE Article 6A.4.2.3) and the system factor (MBE Article 6A.4.2.4) enter the capacity term, why those two factors must not be used to count the same deterioration twice, and how to document assumptions so that a reviewer, and the next engineer, can follow the rating. Factor values in this course are taken from the AASHTO Manual for Bridge Evaluation (MBE) tables as reproduced in AASHTO's published errata and in FHWA's Steel Bridge Design Handbook. Worked-example numbers are illustrative teaching values unless a source is named.

Learning objectives

- Translate inspection data into section properties
- Apply the condition factor correctly
- Avoid double-counting deterioration
- Document assumptions for reviewers

Why deterioration belongs in the rating

The NBIS defines a load rating as "the analysis to determine the safe vehicular live load carrying capacity of a bridge using bridge plans and supplemented by measurements and other information gathered from an inspection" (23 CFR 650.305). The words *supplemented by measurements and other information gathered from an inspection* are the subject of this course. A rating made only from the original plans describes the bridge that was built. A rating that reflects the inspection describes the bridge that exists.

23 CFR 650.313(k) requires each bridge to be rated in accordance with the MBE, and requires an existing bridge to be re-rated within 3 months of an inspection that finds changes warranting a new rating. Section loss is the most common of those changes. The rating engineer therefore needs a repeatable way to decide (1) whether a change in condition warrants a new rating, (2) how to represent the change in the analysis, and (3) which reduction factors apply.

The LRFR capacity term

For the strength limit states the MBE LRFR capacity is

$$C = \phi_c \phi_s \phi R_n$$

with the lower limit $\phi_c \phi_s \geq 0.85$. Here R_n is the nominal member resistance *as inspected*, ϕ is the LRFD resistance factor, ϕ_c is the condition factor and ϕ_s is the system factor (FHWA Steel Bridge Design Handbook, Chapter 18, summarizing MBE 6A.4.2). For the service limit states the capacity is the allowable value f_R from the LRFD specifications, and ϕ_c and ϕ_s are not applied.

Three separate things are hidden in that one line:

- **R_n as inspected.** Measured or estimated section loss reduces the nominal resistance directly. This is where most of the deterioration is accounted for.
- **ϕ_c .** An additional reduction for the *uncertainty* in the resistance of a deteriorated member and for further deterioration likely before the next inspection.
- **ϕ_s .** A reduction (or, with justification, an increase) for the redundancy of the superstructure system. It has nothing to do with deterioration.

Keeping these three ideas apart is the core skill this course teaches.

The condition factor ϕ_c (MBE 6A.4.2.3)

The MBE condition factor table (Table 6A.4.2.3-1) is short:

Structural condition of member	ϕ_c
Good or Satisfactory	1.00
Fair	0.95
Poor	0.85

Where condition information is available only as NBI condition ratings rather than element data, commentary Table C6A.4.2.3-1 gives an approximate conversion based on the superstructure condition rating: **6 or higher** corresponds to Good or Satisfactory, **5** to Fair, and **4 or lower** to Poor. The commentary refers to the superstructure rating by its legacy SI&A item number (Item 59); under the SNBI the corresponding item is B.C.02, Superstructure Condition Rating, which uses the same 0–9 scale.

What the factor is for

The commentary to 6A.4.2.3 explains that the uncertainties of an intact existing member are at least those of a new member, but once a member deteriorates "the uncertainties and resistance variabilities are greatly increased," and deteriorated members "are generally prone to an increased rate of future deterioration." Part of ϕ_c "relates to possible further section losses prior to the next inspection and evaluation." In other words, ϕ_c is a statistical allowance, not a substitute for measuring the loss.

The 0.05 increase for measured section properties

The same commentary states: "If section properties are obtained accurately, by actual field measurement of losses rather than by an estimated percentage of losses, the values specified for ϕ_c in Table 6A.4.2.3-1 may be increased by 0.05 ($\phi_c \leq 1.0$).\" A Fair member with measured losses may therefore use 1.00, and a Poor member 0.90. Several agencies adopt this directly; the West Virginia DOH 2023 load rating manual, for example, restates it and adds that the condition factor "is not intended to be a substitute for using accurately measured section properties."

What the factor does not cover

- The commentary says ϕ_c "accounts for the member deterioration due to natural causes (e.g., atmospheric corrosion). Damage caused by accidents is specifically not considered here." Impact damage (an over-height truck strike, a vessel or debris hit) must be modeled directly in R_n or by a separate engineering evaluation.
- ϕ_c applies at the strength limit states only.

- The MBE errata text notes that use of condition factors "may be considered optional based on an agency's load-rating practice." Always check the owner's load rating manual.

The system factor ϕ_s (MBE 6A.4.2.4)

System factors "are multipliers applied to the nominal resistance to reflect the level of redundancy of the complete superstructure system. Bridges that are less redundant will have their factored member capacities reduced, and, accordingly, will have lower ratings" (MBE C6A.4.2.4). Table 6A.4.2.4-1 gives simplified values for flexural and axial effects:

Superstructure type	ϕ_s
Welded members in two-girder/truss/arch bridges	0.85
Riveted members in two-girder/truss/arch bridges	0.90
Multiple eyebar members in truss bridges	0.90
Three-girder bridges with girder spacing ≤ 6 ft	0.85
Four-girder bridges with girder spacing ≤ 4 ft	0.95
All other girder bridges and slab bridges	1.00
Floorbeams with spacing > 12 ft and noncontinuous stringers	0.85
Redundant stringer subsystems between floorbeams	1.00

Rules for using the table

- The simplified factors apply "only when checking flexural and axial effects at the strength limit state of typical spans and geometries." A constant $\phi_s = 1.0$ is used for shear at the strength limit state.
- For timber bridges $\phi_s = 1.0$ for flexure and shear.
- The system factor for riveted and bolted gusset plates and their connections "for all force effects shall be taken as 0.90" (BR-L05 covers gusset plates).
- The MBE says the tabulated factors are more conservative than LRFD design values and may be used at the evaluator's discretion, *but* when nonredundant superstructures are rated for legal loads using the generalized load factors of Article 6A.4.4.2.3, the Table 6A.4.2.4-1 values "shall be used."
- If the engineer can demonstrate adequate redundancy (the commentary points to NCHRP Report 406), ϕ_s may be taken as 1.0, and in some cases above 1.0, "but in no instance should ϕ_s be taken as greater than 1.2."

The commentary explains the more liberal 0.90 for riveted members and multiple eyebars: "The internal redundancy in these members makes a sudden failure far less likely." It also notes that some agencies treat all three-girder systems as nonredundant regardless of spacing, another point to check in the owner's manual.

From inspection notes to section properties: steel members

The rating engineer rarely receives a tidy table of remaining thicknesses. More often the input is a set of inspection notes, photographs, a few sketches and perhaps an element-level condition state quantity for "Steel Open Girder/Beam." The first job is to turn that material into numbers the analysis can use. The Maine DOT Load Rating Guide puts the governing principle simply: "Only sound material should be considered in determining the nominal resistance of the deteriorated section."

What to ask the inspector for

For a rolled or welded steel girder, the controlling information is usually:

- **Bottom flange thickness and width** at the location of maximum positive moment, and at any location where pack rust, pitting or a hole is concentrated. Measure at several points across the width; corrosion on the top surface of a bottom flange is often worst near the web where debris and water collect.
- **Web thickness** near the bearings, typically in the lower few inches of the web just above the bottom flange. This is where deck drainage and joint leakage concentrate, and where shear and bearing resistance are most sensitive.
- **Bearing stiffener condition**, including the area in contact with the flange. A stiffener with its bottom end corroded away cannot deliver the reaction into the web.
- **Top flange** condition is usually less critical for composite girders in positive moment but matters in negative moment regions of continuous spans.
- **Location along the span.** Loss near midspan reduces flexural capacity; loss near the supports reduces shear and bearing capacity. A note that simply says "10% section loss" without a location cannot be rated properly.

How to measure

Ultrasonic thickness gauges and calipers give direct remaining thickness. Pit depth gauges measure localized loss. A straightedge and feeler gauges can estimate loss on a flange surface. The important distinction for the rating, as shown in the previous section, is whether the losses are *measured* or *estimated as a percentage*: measured losses allow the 0.05 increase in ϕ_c under the MBE commentary.

Building the reduced section

For a composite plate girder in positive flexure, a reduced bottom flange area lowers the plastic moment and, for noncompact sections, the yield moment. The usual approach is:

1. Represent each plate by its average remaining thickness over the length that controls (for flexure, the zone of high moment; isolated pits are usually handled separately).
2. Recompute the section properties (elastic neutral axis, section moduli, plastic neutral axis and plastic moment) using the reduced plates.
3. Recheck section classification. A thinner web may change the web slenderness and the applicable resistance equations. A thinner compression flange may change local buckling behavior.
4. Compute R_n for each limit state with the reduced section, then apply ϕ , ϕ_c and ϕ_s .

For shear near the supports, the reduced web thickness enters the web shear buckling coefficient and the plastic shear force directly, so a modest thickness loss in a slender web can cause a disproportionate loss of shear resistance. Bearing stiffeners should be checked with their remaining effective area and the remaining contact area at the flange.

Holes and perforations

A through-hole in a web or flange is not "section loss" in the averaged sense. It is a discontinuity. Small holes away from high stress may be handled by deducting the hole from the net section; large holes, holes near a bearing, or holes with cracks radiating from them need a local evaluation and may require a temporary repair or support before any rating is issued. Record the hole size and location precisely so the next inspection can show whether it is growing.

From inspection notes to section properties: concrete and prestressed members

Concrete deterioration affects the rating in a different way from steel corrosion. Much of what the inspector sees (cracking, efflorescence, scaling, shallow spalls) may have little effect on flexural resistance, while the deterioration that controls capacity, corrosion of reinforcement or strands, is partly hidden.

Reinforced concrete

- **Exposed reinforcing.** Where a spall exposes bars, the inspector can measure the remaining bar diameter or estimate the percentage of loss. Remove loose rust before measuring.
- **Loss of bond.** A bar exposed over a long length behind a spall may have lost bond. Where the exposed length is near a support or near a bar cutoff, development of the bar may be in question. This is an engineering judgment the rating engineer should make explicit in the file.
- **Concrete loss in the compression zone.** Spalling of the top of a slab or the top flange of a T-beam in positive moment reduces the compression block. For most members this is secondary, but for heavily deteriorated decks acting as the compression flange it can matter.
- **Delamination.** Delaminated concrete over the bars is not sound material and should not be counted, especially for cover concrete that provides bond.

The Maine guide makes a related point about ϕ_c for concrete: a member "may receive a low condition rating due to heavy cracking and spalling or due to the deterioration of the concrete matrix," and such deterioration "may not necessarily reduce their calculated flexural resistance." That is exactly the situation in which ϕ_c , rather than a reduced R_n , carries most of the allowance for deterioration.

Prestressed concrete

For pretensioned beams the critical question is the number of effective strands. Practical rating steps are:

1. **Count broken or exposed strands** at each location. A strand exposed and visibly corroded should be treated as lost unless the engineer has a basis to count it.
2. **Remove lost strands from the section** at the cross-section being checked, and consider the transfer length on either side of a break when deciding where the strand becomes effective again.
3. **Recompute the effective prestress force** and eccentricity, and rerun both the strength check and, for prestressed members, the service checks the owner requires (MBE LRFR includes a Service III check for prestressed concrete at the design level; owners differ on how it is applied at legal and permit levels).
4. **Look for hidden damage:** longitudinal cracks along the strand line, rust staining and hollow-sounding concrete along the bottom flange often indicate corrosion beyond what is visible.

For post-tensioned members, grout voids and tendon corrosion cannot be seen from the surface at all. Those evaluations are outside the scope of a routine rating and usually involve invasive investigation; see the FHWA post-tensioning resources in the reference list of related courses.

Timber

For timber members, decay reduces the sound cross-section, often from the inside (pockets of decay detected by sounding or resistance drilling). Rate the member on the sound section only. Recall that the MBE system factor for timber is 1.0 for flexure and shear, so all of the deterioration allowance for timber comes from the reduced section and the condition factor.

Avoiding double-counting deterioration

The single most common error in rating deteriorated members is counting the same loss twice: once by reducing the section, and again by choosing a low condition factor *because of that same section loss*, and sometimes a third time by lowering the system factor because the bridge "looks bad." Each factor has a defined job, and each piece of deterioration should be assigned to one of them.

A simple allocation rule

Effect	Where it belongs
Measured or estimated loss of material at the section being checked	R_n (reduced section)
Uncertainty in that loss, and probable further loss before the next inspection	ϕ_c
Redundancy of the superstructure system	ϕ_s
Accident damage (impact, fire)	R_n or separate evaluation; not ϕ_c
Deterioration of the riding surface affecting dynamic response	Dynamic load allowance (legal-load rating)

Is applying both R_n reduction and ϕ_c double counting?

No, not by itself. The MBE intends ϕ_c to be applied in addition to the reduced section: the reduced section reflects what was found, and ϕ_c reflects what was *not* found and what will happen next. The Maine guide states the point directly: "The Condition Factor ϕ_c does not account for section loss, but is used in addition to section loss." The MBE's own recognition of this is the 0.05 increase: when losses are measured rather than estimated, part of the uncertainty is gone, so the factor rises.

Where double counting actually happens

- **Inflating loss "to be safe" and then using Poor.** If an inspector reports 10 to 15 percent loss and the engineer models 25 percent to be conservative, then also uses $\phi_c = 0.85$, the uncertainty has been covered twice. Model the best estimate and let ϕ_c do its job, or document why a higher loss is the best estimate.
- **Using the superstructure NBI rating for every member.** The conversion in Table C6A.4.2.3-1 is described as approximate, for use when only NBI ratings are available. A superstructure rated 4 because of one badly corroded exterior girder does not make every interior girder Poor. Where element data or member-specific notes exist, select ϕ_c per member.
- **Applying ϕ_c to an undamaged location.** A girder with heavy loss at the bearing and sound steel at midspan may justifiably use a Poor factor for the shear and bearing checks near the support and a higher factor for the midspan flexure check, provided the owner's practice allows it and the choice is documented.
- **Lowering ϕ_s for deterioration.** The system factor describes the structural system. A two-girder welded bridge is 0.85 whether it is new or old. Do not reduce ϕ_s to reflect corrosion.

The floor on the product

The limit $\phi_c \phi_s \geq 0.85$ exists so that the two factors together do not over-penalize a member. A Poor welded two-girder member would otherwise have $0.85 \times 0.85 = 0.7225$; the floor raises the product to 0.85. Note what the floor does *not* do: it does not limit the reduction of R_n for measured section loss. A severely corroded member can still rate very low, as it should.

Worked example: a corroded rolled-beam bridge

All numbers in this example are illustrative teaching values, not taken from a real bridge or a published example.

A simple-span, four-girder rolled-beam bridge carries a two-lane road. The girders are spaced at 7 ft, so the system factor is 1.00 under "All other girder bridges and slab bridges" (the 0.95 value applies only to four-girder bridges with spacing ≤ 4 ft). The inspection reports:

- Superstructure condition rating 5 (Fair).
- Exterior girder G1: bottom flange top surface pitting at midspan; ultrasonic readings average 0.58 in. against a plan thickness of 0.68 in. (about 15% loss), measured at five points.
- Exterior girder G1: web at the west bearing has a 6-in.-high band of loss just above the flange; caliper readings average 0.30 in. against 0.415 in. plan (about 28% loss).
- Interior girders: light surface rust, no measurable loss.

Step 1: assign each finding

G1 midspan flange loss goes into R_n for flexure. G1 web loss at the bearing goes into R_n for shear and bearing. Interior girders use plan dimensions.

Step 2: select ϕ_c

From the conversion table, a superstructure rating of 5 maps to Fair, $\phi_c = 0.95$. Because both G1 losses were measured (ultrasonic and caliper), the commentary allows $\phi_c = 0.95 + 0.05 = 1.00$ for G1, if the owner's practice permits. For the interior girders, which have no measurable loss, the owner's practice may permit treating them as Good/Satisfactory, $\phi_c = 1.00$, on the basis of member-level inspection information. For this example assume the owner allows both.

Step 3: compute illustrative capacities

Suppose the reduced-section analysis gives these illustrative values for G1:

Check	ϕR_n , plan section	ϕR_n , reduced section	$\phi_c \phi_s$	C
Midspan flexure	1,900 k-ft	1,720 k-ft	1.00	1,720 k-ft
Shear at west bearing	210 k	150 k	1.00 ($\phi_s = 1.0$ for shear)	150 k

The 15 percent flange loss reduced flexural resistance by about 9 percent here, because the web and top flange are unaffected and the plastic neutral axis shifts. The 28 percent web loss reduced shear resistance by about 29 percent, roughly in proportion, and because the web is slender, possibly more depending on the buckling coefficient. In this example the bearing-area web loss, not the midspan pitting, is more likely to control the legal-load rating.

Step 4: the double-counting test

Had the engineer instead (a) modeled a conservative 25 percent flange loss "since pitting is irregular," (b) used $\phi_c = 0.85$ because the bridge "looks Poor," and (c) ignored the measurement credit, the flexural capacity would have been reduced three times for the same pitting. The rating would still be defensible in the sense of being conservative, but it could trigger an unnecessary posting, and under 23 CFR 650.313(l) a posting must be in place within 30 days of the rating. Conservative ratings have real costs.

Step 5: what to record

The rating file should show the measured thicknesses with their locations, the averaging method, the ϕ_c selection and why, the owner policy relied on for the 0.05 increase and for member-specific ϕ_c , and the controlling check.

Worked example: a two-girder welded bridge and the 0.85 floor

All numbers in this example are illustrative teaching values.

A two-girder welded plate girder bridge with a floorbeam-stringer system is rated for legal loads. The main girders fall under "Welded members in two-girder/truss/arch bridges," $\phi_s = 0.85$. Because this is a nonredundant superstructure rated for legal loads with the generalized load factors, the MBE requires the Table 6A.4.2.4-1 system factors to be used unless redundancy is demonstrated by a more rigorous analysis.

The inspection reports superstructure condition rating 4 (Poor) because of heavy pack rust and section loss at several floorbeam connections. The main girder bottom flanges have only light, unmeasurable surface corrosion.

Main girder flexure

- Using the superstructure rating, $\phi_c = 0.85$ (Poor).
- $\phi_c \phi_s = 0.85 \times 0.85 = 0.7225$, which is below the floor, so use **0.85**.
- If instead the owner permits a member-specific selection and the girders themselves are judged Satisfactory, $\phi_c = 1.00$ and $\phi_c \phi_s = 0.85$. In this case the floor makes the two approaches give the same product for the main girders.

Floorbeams

The floorbeams are spaced at 20 ft (illustrative), so floorbeams use $\phi_s = 0.85$ under "Floorbeams with spacing > 12 ft and noncontinuous stringers." The deteriorated floorbeam end connections should be rated with their measured remaining section. If the losses were measured, the Poor factor may be raised to 0.90 under the commentary, giving $0.90 \times 0.85 = 0.765$, still below the floor, so the product is again 0.85. For shear at the connection, $\phi_s = 1.0$ and the product is ϕ_c alone: 0.85, or 0.90 with measured losses.

What this example teaches

- For nonredundant systems the floor often governs, so the choice of ϕ_c matters less in flexure than the accuracy of R_n .
- In shear, where $\phi_s = 1.0$, ϕ_c matters fully. The measurement credit is worth pursuing at connections and bearing areas.
- A bridge with nonredundant members and a Poor rating should also be reviewed for fracture-critical (nonredundant steel tension member) inspection needs; the rating does not replace that inspection program.

When does deterioration warrant a new rating?

23 CFR 650.313(k) requires re-rating within 3 months of an inspection that finds changes warranting a new rating, but it does not define which changes qualify. Owners set that threshold in their load rating manuals. Common triggers include:

- A drop in the superstructure or substructure condition rating, especially across one of the ϕ_c boundaries (6 to 5, or 5 to 4), since that change alone alters the rating under the approximate conversion.

- New or increased section loss at a location that controlled the previous rating, or at a location that was not checked before (for example, a web near a bearing when the prior rating checked only midspan flexure).
- Newly broken or exposed prestressing strands.
- Impact damage, fire damage or flood damage to a primary member.
- A change in dead load: an added overlay, a utility, a new barrier.
- A change in bearing behavior that alters the structural system (frozen bearings, settlement).

Using the previous rating efficiently

Not every condition change requires a full new analysis. If the earlier rating file documents the controlling sections and their capacities, the engineer can often show quickly that a new loss at a non-controlling location does not change the rating. That conclusion should still be documented, dated and signed according to the owner's procedures, so that the 3-month requirement is visibly met.

The inspector–rater loop

The most effective agencies close the loop: the rating engineer tells the inspection team which locations control the rating and what measurements are needed, and inspectors return measured values at those locations at each cycle. The SNBI's emphasis on recording load rating data (the B.LR items, including load rating method) and the NBIS requirement that load ratings be "supplemented by measurements and other information gathered from an inspection" both support this practice. A one-page "rating-critical locations" sheet in the inspection file is a simple way to implement it.

Documenting assumptions for reviewers

A deteriorated-member rating involves more judgment than a plan-based rating, and the documentation should make that judgment visible. A reviewer, or the engineer who re-rates the bridge in four years, should be able to reproduce every number. A practical documentation package includes:

1. **Inspection source.** Report date, inspector, and the specific findings used. Attach photographs of each location that changed the section.
2. **Measurement record.** Instrument type (ultrasonic gauge, caliper, pit gauge), number of readings, locations on a sketch, and the value used. State whether losses were measured or estimated, since this determines eligibility for the ϕ_c increase.
3. **Section modeling.** How readings were averaged, how isolated pits and holes were treated, which portions of concrete were treated as unsound, and how many strands were removed.
4. **Factor selection.** ϕ_c and ϕ_s for each member and limit state, the table row used, whether the 0.05 increase was taken, and the owner policy relied on. Note where the $\phi_c\phi_s \geq 0.85$ floor governed.
5. **Exclusions.** Effects deliberately not included in ϕ_c (for example accident damage modeled directly) and why.
6. **Controlling result.** The controlling member, location, limit state and vehicle, and a comparison with the previous rating.
7. **Recommendations.** Locations to measure at the next inspection, and repair or monitoring recommendations if the rating is near a posting threshold.

A reviewer's checklist

- Does every section reduction trace to a specific, dated inspection finding?

- Is the same deterioration counted only once?
- Is $\phi_s = 1.0$ used for shear, and is ϕ_s chosen from the system, not the condition?
- Is the floor on $\phi_c \phi_s$ applied?
- Were service checks for prestressed members run with the reduced strand count where the owner requires them?
- If the result triggers posting, is the 30-day clock in 650.313(l) being tracked?

These items are good practice drawn from the requirements discussed in this course; they are not a quotation from any one manual. Use your owner agency's checklist where one exists.

Worked example: a prestressed beam with broken strands

All numbers in this example are illustrative teaching values.

A simple-span bridge has six pretensioned I-beams spaced at 8 ft, so $\phi_s = 1.00$ ("All other girder bridges"). An over-height vehicle struck the exterior beam, spalling the bottom flange over a 3-ft length near midspan. The inspector reports two strands severed and one strand exposed with surface rust but intact. Elsewhere the beams are in good condition, and the superstructure rating was lowered from 7 to 5 because of the impact.

Step 1: recognize the type of damage

This is accident damage. The MBE commentary says ϕ_c "accounts for the member deterioration due to natural causes" and that "Damage caused by accidents is specifically not considered here." The impact must therefore be modeled directly in R_n , not covered by lowering ϕ_c .

Step 2: model the section

- Original strand count in the bottom flange: 24 (illustrative).
- Remove the 2 severed strands at the damaged section. Near the break, a severed strand regains effective force only over its transfer length, so the reduced strand count applies over a zone extending past each side of the damage, not just at the cut.
- The exposed, intact strand: the engineer must decide whether to count it. With only surface rust and no measured loss of area, counting it may be reasonable for now, but the file should say so and flag the strand for re-inspection. A conservative engineer might discount it; that is a judgment, and it should be stated, not hidden.
- Remove the spalled concrete from the bottom flange in the section model, and check whether the loss affects the compression zone (usually not, in positive moment) or the strand cover for the remaining strands.

Step 3: choose ϕ_c

The conversion table would map the new superstructure rating of 5 to Fair, $\phi_c = 0.95$. But the rating drop was caused entirely by the impact, which has already been modeled in R_n . Applying 0.95 to the damaged beam for the impact would be counting the same damage twice in spirit, since ϕ_c is not intended for accidents. Where the owner allows a member-specific selection based on natural deterioration, the engineer may justify $\phi_c = 1.00$ for all beams and document the reasoning. Where the owner requires ϕ_c from the NBI superstructure rating, the engineer should follow that policy and note in the file that it is conservative.

Step 4: run the checks

Rerun strength flexure with the reduced strand count and section, and any service checks the owner requires for prestressed concrete. Suppose the illustrative results show the damaged beam's flexural rating factor for the legal loads falls from 1.35 to 1.08. The bridge does not need posting, but the margin is now small and the damage could grow if the exposed strand corrodes.

Step 5: recommend

Recommend a repair (patching to restore cover, and evaluation of strand splicing or external strengthening if required by the owner) and an interim inspection of the damaged area. Record that the rating depends on the exposed strand remaining intact.

Element-level data, condition states and the BIRM

Since the 2012 surface transportation law (MAP-21) required element-level data on National Highway System bridges, many inspection files contain element condition state quantities from the AASHTO Manual for Bridge Element Inspection (MBEI), in addition to NBI condition ratings. Element data describe how much of a given element is in each of four condition states, from CS1 (good) to CS4 (severe). This information is far more useful to the rating engineer than a single superstructure number, because it shows where and how extensive the deterioration is.

Using element data

- **Locate the worst quantities.** An element record showing a small quantity in CS4 for a steel girder tells the engineer that somewhere there is severe corrosion or section loss. The condition state alone does not give a thickness; the engineer still needs the inspection notes and, ideally, measurements.
- **Do not convert element states to ϕ_c mechanically.** The MBE table expresses ϕ_c by "structural condition of member" (Good or Satisfactory, Fair, Poor), and the approximate NBI conversion is offered for when only NBI ratings are available. Element condition states use different definitions. If the owner has a policy correlating element data to ϕ_c , follow it; otherwise use engineering judgment based on the member's actual condition and document it.
- **Use element notes to target measurements.** A CS3 or CS4 quantity at a girder end tells the inspector where to bring the ultrasonic gauge next time.

What the BIRM contributes

The FHWA Bridge Inspector's Reference Manual (BIRM) is the standard reference for how inspectors identify and describe deterioration: corrosion and section loss in steel, cracking, spalling, delamination and reinforcement corrosion in concrete, and decay in timber. It also describes the tools inspectors use. Rating engineers benefit from knowing the BIRM terminology, because the descriptions in an inspection report ("pack rust," "pitting," "delamination," "efflorescence") imply different consequences for R_n . For example, efflorescence by itself indicates water passing through concrete, not necessarily any reduction in capacity, while delamination over reinforcement indicates that the concrete cover is no longer sound and the bars beneath may be corroding.

Common pitfalls and quick answers

"The inspection says 20% section loss. Do I reduce the whole girder by 20%?"

No. Ask where. A loss percentage without location and extent cannot be modeled responsibly. If no better information is available, model the loss at the controlling locations for each limit state, state the assumption, and request measurements at the next inspection. Remember that an *estimated* percentage does not qualify for the 0.05 increase to ϕ_c .

"Can I skip ϕ_c because I measured everything?"

Only if the owner's practice makes condition factors optional, which the MBE permits. Under the MBE commentary, measured losses earn an increase of 0.05, capped at 1.0. A Fair member with measured losses reaches 1.00; a Poor member reaches only 0.90.

"The bridge is a three-girder bridge at 9 ft spacing. Is ϕ_s 0.85?"

The tabulated 0.85 row is for three-girder bridges with girder spacing of 6 ft or less. A three-girder bridge at wider spacing falls under "All other girder bridges," 1.00, under the table. However, the MBE commentary notes that some agencies consider all three-girder systems nonredundant irrespective of spacing. Check the owner's manual.

"My service check for a prestressed beam fails after removing strands. Does that force a posting?"

That depends on how the owner applies service limit states at the legal load level. MBE LRFR treats some service checks differently at the design, legal and permit levels, and owners adopt their own policies. The point for this course is that the reduced strand count must be used consistently in whatever checks the owner requires.

"Can a high system factor offset deterioration?"

Only redundancy can justify a ϕ_s above the tabulated value, and only up to 1.2 with a demonstrated basis. A higher ϕ_s is not a way to recover capacity lost to corrosion; it is a recognition that the system has reserve beyond the member check.

"What if the deterioration is too severe to model?"

If remaining section cannot be determined with reasonable confidence, for example a web perforated at a bearing with cracks, a rating based on assumed values may not be appropriate. The engineer should recommend immediate action to the owner (temporary shoring, restriction or closure under the owner's procedures and 23 CFR 650.313) and a more detailed investigation.

How deterioration flows through the rating levels

An LRFR rating is carried out at several levels: design load rating (inventory and operating with HL-93), legal load rating, and, where needed, permit load rating. Deterioration affects all of them through the same capacity term, but the consequences differ.

Design load rating

The design load rating is a screening step. With the reduced R_n and the applicable ϕ_c and ϕ_s , a deteriorated member that still shows an HL-93 inventory rating factor of 1.0 or more is generally satisfactory for legal loads, and the MBE screening logic

allows the legal-load step to be skipped. Deterioration often pushes a member below that screening threshold for the first time, which is why the legal-load rating becomes necessary as a bridge ages.

Legal load rating

This is where deterioration most often has a practical effect, because legal-load rating factors below 1.0 lead to posting (BR-L03). Two inputs that interact with the condition of the bridge deserve a second look at this level:

- **Dynamic load allowance.** For legal-load rating the MBE allows the dynamic load allowance to be based on the riding surface condition (BR-L03 discusses the published options). A deteriorated deck and approach slab may raise the allowance. This is a separate effect from member deterioration and should be selected from the deck and approach notes, not from the girder section loss.
- **System factor for nonredundant structures.** As covered above, nonredundant superstructures rated with the generalized legal-load factors must use the Table 6A.4.2.4-1 system factors.

Permit load rating

Permit reviews on deteriorated bridges should use the same reduced sections and factor selections as the legal-load rating, unless new inspection information is available. A permit move across a bridge with a recently found loss should not be approved on the basis of a rating that predates the finding.

Ratings and the inspection interval

The condition factor anticipates further deterioration "prior to the next inspection and evaluation." If an owner shortens the inspection interval for a deteriorating bridge, the period over which further loss can occur is shorter. The MBE condition factor table does not change with interval, but this is one reason owners pair low ratings with increased inspection frequency: the rating stays reliable only if the inspection keeps it current.

Putting it together: a five-step workflow

The examples in this course follow the same sequence, which can be used for any deteriorated member:

1. **Classify each finding.** Is it natural deterioration, accident damage, a change in dead load, or a change in structural behavior? Only natural deterioration belongs in the ϕ_c discussion.
2. **Model what was found.** Build the reduced section from sound material only, at the locations that control each limit state, using measured values where available.
3. **Select ϕ_c for what was not found.** Use Table 6A.4.2.3-1, the approximate NBI conversion where only NBI ratings exist, and the 0.05 increase when losses were measured, following the owner's policy.
4. **Select ϕ_s from the system.** Use Table 6A.4.2.4-1 for flexure and axial effects, 1.0 for shear, 0.90 for gusset plates, and apply the floor $\phi_c\phi_s \geq 0.85$.
5. **Document and close the loop.** Record measurements, assumptions and factor choices; identify the controlling location; and tell the inspection team what to measure next time.

Following this sequence keeps each piece of deterioration in exactly one place, makes the rating reproducible, and avoids both unconservative ratings and the costly, unnecessary postings that come from counting the same loss two or three times.

Key takeaways

- Deterioration enters the LRFR strength capacity $C = \phi_c \phi_s \phi R_n$ mainly through a reduced, as-inspected R_n built from sound material only.
- ϕ_c (MBE Table 6A.4.2.3-1): 1.00 Good/Satisfactory, 0.95 Fair, 0.85 Poor; approximate NBI conversion 6+ / 5 / 4 or lower; +0.05 (max 1.0) when losses are field-measured.
- ϕ_c covers uncertainty and future deterioration from natural causes, not accident damage, and is applied in addition to section loss.
- ϕ_s (MBE Table 6A.4.2.4-1) reflects system redundancy, not condition; use 1.0 for shear, 0.90 for gusset plates, never above 1.2; $\phi_c \phi_s \geq 0.85$.
- Assign each finding to one factor, select ϕ_c per member where data allow, and document measurements, locations, factor choices and owner policy.

References

1. AASHTO, The Manual for Bridge Evaluation, 3rd Edition, 2018 (with interim revisions)
2. FHWA, Bridge Inspector's Reference Manual (BIRM), FHWA-NHI-12-049, 2012 (as revised)
3. FHWA, Steel Bridge Design Handbook, Chapter 18: Load Rating of Steel Bridges, FHWA-HIF-16-002 Vol. 18, 2015
4. AASHTO, Manual for Bridge Evaluation, Third Edition, Errata (November 2021)
5. Maine DOT, Load Rating Guide, April 2015
6. West Virginia DOH, Bridge Load Rating Manual, 2023

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.