Research Stage 1 Problem Statement

PROPOSED TITLE: Refinement of Seismic End Cross-Frame Design for Continuous Steel Bridges Using Ductile Superstructure Behavior and Targeted Testing

1. Concisely describe the transportation issue (including problems, improvements, or untested solutions) that Oregon needs to research.

Current seismic design practice for continuous steel bridges in Oregon typically assumes plastic hinges form in the columns (Type 1) and treats the steel superstructure—including end cross frames or diaphragms—as capacity-protected. In applying column plastic hinge demands directly to the pier cross frames, the superstructure is idealized as stiff, which places the bridge on the high-acceleration, short-period side of the response spectrum and produces very large seismic forces in columns, foundations, girders, and cross frames. Because end cross frames are not actually integral with the pier cap, this assumption leads to oversized, very stiff cross frames that can make the girder webs and flanges the unintended weak link, increasing risk of undesirable superstructure damage and driving up costs. Recent research on conventional and ductile end cross frames (MCEER-08-0001, MCEER-08-0002, CCEER-14-04) shows that treating the end cross frame itself as a ductile element and allowing the steel superstructure to remain flexible reduces seismic demand and improves overall performance. However, current AASHTO and ODOT provisions do not provide a clear procedure to design ductile end cross frames, determine appropriate design forces, or verify superstructure drifts and deformations. Oregon needs applied research, supported by targeted testing, to develop and codify a rational, safe, and economical seismic design approach for end cross frames in continuous steel bridges.

2. What final product or information needs to be produced to enable this research to be implemented?

This research needs to produce a practical, implementable design methodology for seismic end cross frames (or diaphragms) in continuous steel bridges that intentionally uses the steel superstructure's flexibility and the end cross frame's ductility as part of the seismic force-resisting system. The primary products should include:

- Clear criteria and procedures for when and how end cross frames may be designed as **ductile elements**, as opposed to capacity-protected elements directly resisting column plastic hinge demands.
- Rational methods to determine **design forces and deformation demands** for ductile end cross frames, based on system behavior (target ductility, period shift toward the long-period side of the ARS curve, and effective damping).
- Procedures to check **superstructure deformations and drift limits**, including global bridge displacements and local girder web/flange demands, to ensure that inelastic behavior is concentrated in the end cross frames and that girders, webs, bearings, and connections remain within acceptable limits.

To ensure implementation, the research should translate analytical and experimental findings into updates and supplements to existing standards and guidance used in Oregon. Expected implementation products include:

- Draft revisions or additions to the **ODOT Bridge Design and Drafting Manual** for seismic design of continuous steel bridges at piers, specifically for end cross-frame/diaphragm design and detailing.
- Recommended language and design examples compatible with the **AASHTO LRFD Bridge Design Specifications** and **AASHTO Guide Specifications for LRFD Seismic Bridge Design** (Types 2 and 3 strategies), clarifying modeling assumptions, force-deformation relations, and drift checks for ductile end cross frames.
- A set of **standard (or concept) details** and **worked design examples**, including a full comparison between the current capacity-protected approach and the proposed ductile end cross frame approach for a typical 3-span continuous steel bridge (e.g., 150–280–150 ft), showing differences in cross-frame sizes, column and foundation demands, and overall cost.

These products will allow ODOT bridge designers, their consultants, and reviewers to consistently apply a modern ductile end cross frame design approach on Oregon projects and to justify changes to manuals, standards, and design practice with Oregon-specific evidence.

3. (Optional) Are there any individuals in Oregon who will be instrumental to the success of implementing any solution that is identified by this research? If so, please list them below.

Name	Title	Email	Phone
Alex Lim	Steel Bridge Standards Engineer, ODOT Bridge Engineering	Alex.K.LIM@odot.oregon.gov	971-283-5518

4. Other comments:

Recent analytical and experimental work has already identified concerns with current practice and demonstrated the potential benefits of ductile end cross frames. The 2008 MCEER reports (MCEER-08-0001 and MCEER-08-0002) on the seismic performance of steel girder bridge superstructures with conventional and ductile end cross frames, and the 2014 CCEER report (CCEER-14-04) on nonlinear evaluation of proposed ductile end cross frame procedures, show that enabling ductile behavior in end cross frames and explicitly recognizing the steel superstructure's flexibility can significantly reduce force demands on columns, foundations, and superstructure components. These studies indicate that the actual load path is more complex than what is currently assumed when directly transferring column plastic hinge forces to capacity-protected cross frames; the superstructure participates in distributing and dissipating seismic demand, and overly stiff cross frames can attract forces and shift inelastic response into girder webs and flanges.

The proposed research would build on this foundation to develop Oregon-specific, code-compatible procedures and detailing guidance, supported by targeted physical testing. A representative **3-span**

continuous steel plate girder bridge (span lengths approximately 150–280–150 ft) would be used as a prototype. Two parallel design cases would be developed and compared:

- **Current (capacity-protected) case:** End cross frames designed to resist full column plastic hinge overstrength demands, consistent with current Type 1 practice and typical assumptions that the superstructure remains essentially elastic. This typically yields very heavy inverted K-type cross frames and large demands on girders, columns, and foundations.
- **Proposed (ductile end cross frame) case:** End cross frames intentionally designed as ductile members, with the steel superstructure modeled as flexible and participating in energy dissipation. In this case the effective period lengthens, the design spectral demand moves to the long-period (lower acceleration) side of the ARS curve, and overall seismic forces on columns, foundations, and superstructure are reduced.

A targeted test program is expected to be needed to support and calibrate the design procedure. This may include:

- Cyclic tests of a full-scale or large-scale **end cross frame with connected girder stubs** and realistic connection details, designed to exhibit controlled ductility and to capture member forces (top chord, diagonals, bottom chord), connection behavior, and failure modes.
- A large-scale **column–superstructure subassembly test**, where column plastic hinging and end cross-frame yielding can occur, to measure how column plastic hinge demands redistribute through different cross-frame configurations (K-type, X-type, solid plate diaphragm) and stiffness levels.
  Results from these tests, combined with nonlinear time-history or pushover analyses of the 3-span prototype bridge under relevant Cascadia and crustal records, would be used to derive simplified design equations and drift-check procedures compatible with AASHTO and ODOT documents.

A high-level cost and safety comparison for the prototype 3-span 150–280–150 ft bridge illustrates the potential impact. Under current capacity-protected practice, end cross frames at each pier may require heavy sections and thick connection plates, with total diaphragm steel on the order of several times what would be required for a ductile detail. The stiff cross frames keep the period short and result in high column moments and base shears, driving larger column sizes and foundations. Conceptually, moving to a ductile end cross frame approach—using the same bridge geometry and site hazard—lengthens the system period and exploits additional hysteretic damping. This shifts the design point on the ARS curve toward the long-period region, reducing seismic forces throughout the system. That reduction translates into smaller end cross frames, lower column demands, and smaller foundations. For a typical bridge in this size range, this can reasonably be expected to reduce the seismic-driven cost of cross frames, columns, and foundations on the order of tens of percent, improving the cost-competitiveness of steel superstructures relative to competing concrete options.

From a safety perspective, the current approach of making end cross frames very strong and stiff while assuming an idealized load path from column hinges can inadvertently make the girder webs and flanges the weakest link. In a major earthquake, this can lead to web buckling, flange fractures, or connection damage in the main girders—damage that is difficult to detect, challenging to repair, and potentially critical to the integrity of the bridge. Such failure modes increase the risk of partial or progressive girder failure and long closures for inspection and repair, directly affecting the traveling public and emergency response. In contrast, a well-defined ductile end cross frame design approach concentrates inelastic behavior in purposely detailed, accessible, and replaceable components. This improves seismic performance, simplifies post-event inspection and repair, and reduces the likelihood that main girders, columns, or foundations will experience damaging inelastic demands.

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5. State of Oregon Decision Making Lenses

State decision making lenses are a part of the state of Oregon's policy structure. State policy and federal policy are not always aligned. The state will prioritize research according to state policy, however ODOT may be required to skip prioritized proposals based on constraints placed on the use of federal funds. If state funds are available ODOT will attempt to fund prioritized research that is deemed ineligible for federal funding.

Please complete the following three sections. Your answers to these questions will be applied on a programmatic basis to support agency decisions. Answering yes to the questions below is not required. Resolving a narrowly focused technical research problem may meet agency needs without answering yes to any of the following questions. The ODOT Research Section will seek a balanced portfolio some projects will answer yes to one of the three categories below (e.g. climate, equity, and/ or safety) and other projects in a different category.

We are looking for an overall program balance and no one project is expected to balance all categories. Generally, a research problem statement is expected to be able to answer yes with clear and verifiable information in only one of the three categories below, some projects may be able to answer yes in two or even three categories. Some projects (i.e. needs focused on specific elements of infrastructure design), may have no 'yes' answers but may still be a high value research need.

Climate

Oregon recognizes the climate crisis and makes systemic changes to reduce emissions caused by travel. To that end, we seek research that reduces carbon emissions from construction activities and materials, and from maintenance equipment and operations. Oregon envisions a transportation system that is resilient, this means a system that is durable in the face of seismic events and extreme weather to avoid negative impacts, withstand them or bounce back quickly to resume system function. We seek research that improves the ability of the transportation system to adapt or cope with more frequent and extreme weather events. This may include innovations in data and data sharing, construction materials and project design, communication, emergency planning and response, and more. Similarly, we seek research that avoids negative impacts on key habitats and ecosystems that can buffer or reduce damage to infrastructure and improve environmental conditions for wildlife and native vegetation. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan and Oregon Transportation Plan.

5a. Will addressing the transportation issue identified as a need in Question 1 develop, or **validate methods for the estimation, measurement, or monitoring** of transportation generated greenhouse gases (GHG)?

☐Yes ☒No ☐Unsure

5b. If climate or GHG is not the focus of this **transportation issue** identified in this problem statement, will the research apply a GHG analysis to transportation infrastructure, planning, operations, maintenance, or materials?

☐Yes ☒No ☐Unsure

5c. Will addressing the **transportation issue** include development or testing of construction practices, methods, or materials to establish potential reductions in greenhouse gas emissions?

☐Yes ☒No ☐Unsure

5d. Will solving the **transportation issue** in question 1 study or support the reduction of vehicle miles traveled and single occupancy vehicle travel or support transition to electric vehicles (or other types of zero emission vehicles) or low-carbon alternative fuels?

☐Yes ☒No ☐Unsure

5e. Will the solving the **transportation issue** in question 1 lead to work that will support, measure, or monitor, transportation system resilience in response to expected climate events, effects, or natural disasters in general?

☒Yes ☐No ☐Unsure

5f. Will solving the **transportation issue** in question 1 lead to work that may result in better environmental conditions for wildlife and native vegetation?

☐Yes ☒No ☐Unsure

5g. If you answered yes to any of the climate questions above or can provide alternative details related to climate, please provide additional information:

This research directly supports transportation system resilience to seismic events, which are a major natural hazard for Oregon's transportation network. By shifting from an over-stiff, capacity-protected superstructure approach to a rational, ductile end cross frame design methodology, the project aims to lower seismic demands on critical bridge elements (columns, foundations, main girders), reduce the likelihood of severe damage or collapse, and speed post-earthquake recovery. Concentrating ductility in replaceable end cross frames improves the ability of bridges to withstand strong earthquakes and return to service more quickly, aligning with the resilience objectives in the Oregon Transportation Plan and ODOT's Strategic Action Plan. Although greenhouse gas reduction is not the focus, the project clearly targets improved performance under natural disasters.

Equity

Equity can have many dimensions and impacts relating to communities and transportation. It is important that problem statement proposals clearly explain the equity dimensions or impacts being examined. Oregon commits to social equity in the OTP, specifically to *improve access to safe and affordable transportation for all, recognizing the unmet mobility needs of people who have been systemically excluded and underserved. Create an equitable and transparent engagement and communications decision-making structure that builds public trust*. We seek research that studies elements of this goal or applies analysis to specific transportation topics to ensure the resulting research recommendation is consistent with agency equity goals. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan and Oregon Transportation Plan.

5h. Is the **transportation issue** identified as a need in Question 1 specifically focused on transportation equity?

☐Yes ☒No ☐Unsure

5i. If the **transportation issue** is not focused on transportation equity, will the primary topic be assessed for equity benefits or impacts within the research project?

☐Yes ☒No ☐Unsure

5j. Is the implementation of potential findings from this research likely to directly involve participation from an identified group that would benefit from an equitable process or outcome?

☐Yes ☒No ☐Unsure

5k. Is the intended final product or information expected to support ODOT's equity efforts (Including but not limited to supporting one of the equity related objectives of the ODOT's Strategic Action Plan or Oregon Transportation Plan) ?

☐Yes ☐No ☒Unsure

5l. If you answered yes to any of the equity questions above or can provide alternative details related to equity, please provide additional information:

This problem statement is primarily a technical structural design and seismic performance issue. Any equity benefits will be indirect—more resilient bridges with shorter closure times benefit all communities, including those that may have limited alternate routes. However, equity is not the primary focus of the proposed research.

Safety

Research outcomes may include interventions and countermeasures to prevent or reduce the frequency of crashes or other causes of transportation-related injury or death; or may include measures to reduce severity of injury (including prevention of death) after a crash or other injurious event. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan, Oregon Transportation Safety Action Plan and Oregon Transportation Plan.

5m. Will solving the **transportation issue** in question 1 support improving **safety culture** for either transportation workers or the traveling public?

☒Yes ☐No ☐Unsure

5n. Will the solving the **transportation issue** support improving safety through **healthy and livable communities**?

☐Yes ☐No ☒Unsure

5o. Will solving the **transportation issue** support improving safety through using **best available technologies**?

☒Yes ☐No ☐Unsure

5p. Will solving the **transportation issue** support improving safety through **communication and collaboration**?

☐Yes ☐No ☒Unsure

5q. Will solving the **transportation issue** support improving safety through **investing strategically**? 5r. If you answered yes to any of the safety questions above or can provide alternative details related to safety, please provide additional information:

The proposed research directly addresses structural safety for bridges subjected to strong earthquakes. Under current capacity-protected practice, very stiff end cross frames can shift inelastic demands into steel girder webs and flanges, leading to damage modes (local buckling, fractures, connection failures) that threaten the integrity of the main load-carrying system and are difficult to repair. This increases the risk of serious damage or collapse and prolonged closures after major events, directly affecting the traveling public and emergency response. By defining and validating a ductile end cross frame design approach—including test-based design forces, drift checks, and detailing requirements—the research will concentrate inelastic behavior in intentionally ductile, replaceable components, reduce unintended damage in primary members, and improve the reliability of critical lifeline bridges. The work applies best-available nonlinear analysis and testing technologies and will help ODOT invest strategically in measures that provide more safety benefit per dollar than simply over-strengthening columns, foundations, and superstructure components.

6. Corresponding Submitter's Contact Information:

Name:	Alex Lim
Title:	Steel Bridge Standards Engineer
Affiliation:	ODOT – Bridge Engineering
Telephone:	971-283-5518
Email:	Alex.K.LIM@odot.oregon.gov

7. ODOT Sponsor Contact Information (Required if Submitter is not an ODOT employee)

Name:	
Title:	
Crew Number:	
Telephone:	
Email:	

PLEASE SUBMIT THE COMPLETED FORM BY EMAIL TO: odotnewresearch@odot.oregon.gov

This form is not a grant application or contract document. Please do not include proprietary information on this form. Once this form is received ODOT may revise and publish the problem statement. If selected, ODOT will assign investigator(s) of the department's choosing to conduct research.