Challenges of Designing and Building Bridges in Alaska

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ABSTRACT: Alaska's short construction season, remote locations, frozen ground, and high seismic zones require innovative approaches to bridge design. Over the years, the Alaska Department of Transportation & Public Facilities (DOT&PF) Bridge Section has developed standard design approaches for their unique circumstances. This paper highlights the DOT&PF's experience with addressing these numerous concurrent design challenges, including research projects that have been useful in verifying the anticipated performance of these systems.

INTRODUCTION

Each bridge in Alaska offers a number of design and construction challenges, many of which are not specifically addressed by design codes. However, the bridge engineers at the Alaska Department of Transportation & Public Facilities have accumulated decades of experience dealing with these challenges. Their knowledge, in combination with research efforts to verify their design approaches and assumptions, has led to standard design methods that address problems such as seismic conditions, short construction seasons, temperature extremes, remote construction sites, and frozen ground.

CHALLENGES

GEOGRAPHY – Although there are only approximately 1,000 state and locally-owned highway bridges in Alaska, these bridges are spread over a geographic area of 586,400 square miles. In other terms, the state of Alaska is roughly equal to one-fifth of the 48 conterminous United States or an area larger than Texas, California, and Montana combined. A further challenge for access is that some bridge sites are not on the road system, meaning they are accessible only by boat or plane. The term "remote" bridges refers to these bridges off the road system, as well as some bridges in locations on the road system, but several hundred miles from the nearest commercial services.

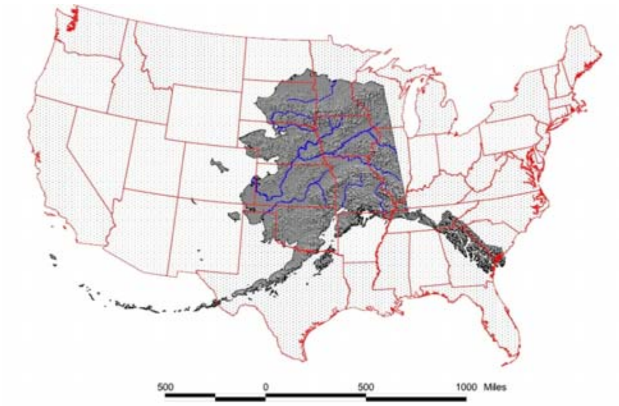

Figure 1 – Alaska Superimposed over the Contiguous United States (USDA, NRCS)

The obvious challenge with this vast geographic area is that contractors have to plan for the logistics and cost of bringing construction materials and equipment long distances. If transport to a site is available by sea only, the contractor may only have a short window in the summer months when waterways are thawed. Additionally, if the contractor needs a crane or other heavy equipment on the jobsite, they may be relinquishing use of that equipment for any other job when return transport of the equipment is not possible until the next summer. In some extreme cases, transport of bridge materials is only possible by cargo plane.

The same geographic challenges from construction arise during long-term maintenance of bridges, but the large distances can have even an even greater impact on routine maintenance costs. The economics of a large construction project may justify sending equipment, such as an asphalt paving machine, to a remote site, but routine maintenance could not justify this expense. It would be too expensive and impractical to return such equipment to remote locations, especially in this example since other options like timber decks are available. In many locations within the state, it is critical to select bridge types and features that require the least amount of long-term maintenance, even if the initial cost is higher.

CLIMATE – Long winters and short summers in Alaska impact the construction season as well as access. Excluding permafrost areas, where the ground is permanently frozen for two or more years, the ground can remain frozen until May with snow falling again in September or October. While contactors usually have the experience and means to work in cold temperatures, it is often so impractical and expensive that they avoid cold weather construction unless absolutely necessary.

Extreme cold temperatures, for example -80°F, have an impact on material properties as well. The temperature extremes must be considered in some aspects of design beyond the requirements of the *AASHTO LRFD Bridge Design Specifications*.

ENVIRONMENTAL CONSTRAINTS – Available construction time can be further reduced by so called “fish windows”. A fish window, the time allotted to the contractor to do in-water work in streams with essential fish habitat, is determined by the applicable environmental agency and varies depending on when the fish in the stream spawn. Essential fish habitat streams are common in both rural and urban Alaska. This limitation to in-water work makes it essential that piers and riprap can be installed quickly. Otherwise extending a project into two constructions season becomes necessary.

SEISMIC ZONES – By far the most significant influence to the way bridges are designed in Alaska has to do with the state’s seismic activity. Alaska is the most seismically active state in the United States and experienced North America’s largest earthquake (moment magnitude 9.2) in 1964. Not only was the 4 minutes of shaking during the 1964 Earthquake a factor, but the subsequent liquefaction, landslides, tsunami, and aftershocks also contributed to the loss of life and extensive property damage. Table 1 lists some of the larger earthquakes in Alaska since the 1964 Earthquake.

Date	Location	Magnitude
January 5, 2013	Queen Charlotte Fault	7.5
June 24, 2011	Fox Islands	7.3
December 19, 2007	Andreanof Islands	7.2
August 2, 2007	Andreanof Islands	6.7
June 28, 2004	Queen Charlotte Fault	6.8
November 17, 2003	Rat Islands	7.7
November 3, 2002	Denali Fault	7.9
1999 – 2001 Series	Kodiak Island	7.0±
February 4, 1965	Rat Islands	8.7
March 27, 1964	Great Alaska Earthquake	9.2

Table 1 – Notable Alaskan Earthquakes (Alaska Earthquake Information Center)

The frequency and magnitude of earthquakes in Alaska means that emphasis is justifiably placed on seismic design. In general the main Alaskan highways do not have alternate routes. If any bridge on these routes were to be taken out of service, transportation would be severely impacted.

SOLUTIONS

A combination of approaches is necessary to address the bridge design and construction challenges in Alaska, but perhaps the most significant have been the adoption of prestressed concrete decked bulb-tee girders and concrete-filled steel pipe pile bents as preferred superstructure and substructure types.

PRECAST PRESTRESSED CONCRETE DECKED BULB-TEE GIRDERS. Alaska has been using decked bulb-tee girders since the early 1970s when they were first shipped to Alaska from the state of Washington. These precast, prestressed concrete girders are similar to concrete I-girders, but the upper flange is much wider, thereby serving as the bridge deck. Using this girder shape eliminates the need to cast and cure a conventional bridge deck, which greatly accelerates construction of the superstructure. In addition, by being precast, the entire superstructure has higher strengths (typically f'c > 8,000 psi) and better quality control than cast-in-place bridge decks. While there is an experienced prestressed girder fabricator in Alaska, steel bridges are typically fabricated outside Alaska. When the need to ship steel girders from out of state is eliminated, in-state precast concrete girders offer considerable savings.

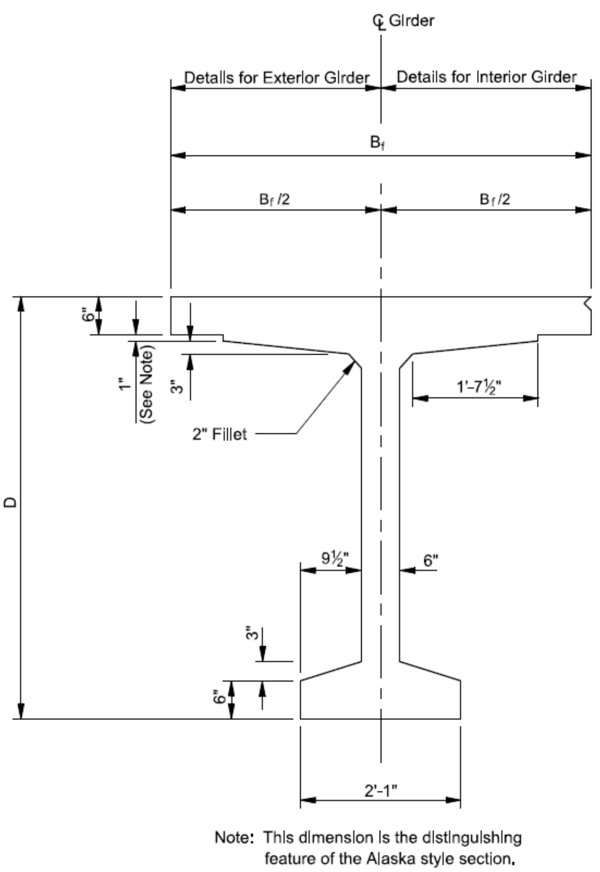

Figure 2
Standard Alaska-Style Precast Prestressed Decked Bulb-Tee Section

Shear keys and tabs along the longitudinal joints of the interior girder flanges are used to connect adjacent girders. The shear keys are typically spaced at 4 feet and contain steel inserts cast in the concrete flange. Steel plates are then welded to the inserts of the adjacent flanges for a rigid connection. Next the shear keys and longitudinal joints are filled with high-strength grout to complete the shear transfer and for corrosion protection. Most bulb-tee bridges then receive a waterproofing membrane and asphalt. If applied correctly, the membrane and asphalt has proven to be effective at keeping water from entering the joints and underside of the superstructure. Experience has shown that the girders act as a uniform superstructure, even under seismic loading.

While the deck cannot be fully inspected when covered with asphalt, the undersides of the flanges do allow inspection. Unlike concrete box beams and stay-in-place deck forms for concrete decks, at least part of the deck is visible when an asphalt overlay is present.

<u>Bulb-Tee Geometry</u> – The top flange width of decked bulb-tee girders typically varies from 5.5 feet to 7.5 feet with a maximum possible width of 8.5 feet. Because the adjacent girders tough, the girder spacing is also equal to the width of the top flange. A typical 2-lane bridge usually consists of 5 or 6 girders, depending on the length of the girders and required roadway geometry. Girders precast in Alaska come in standard depths of 42 inches, 54 inches, and 66 inches. Different girder depths are available in Pacific Northwest states, but these girders also have slightly different typical sections. If an Alaska-style girder is designed for a project and the contractor proposes to use a Washington-style girder (i.e., made in Washington state), the engineer must compare how the different girder shape will affect the bridge geometry and girder design.

The standard length of Alaska-style decked bulb-tee girders depends on the depth. The 42-inch girders can reach spans of around 90 feet; the 54-inch girders span up to approximately 125 feet; and the 66-inch girders can span up to 145 feet. Longer span lengths are technically feasible, but transportation from the precaster to the job site becomes an issue. The single precaster in Alaska is also limited by their existing form lengths.

Despite the numerous advantages, there are some disadvantages of decked bulb-tee girders:

- They are heavy and bulky to transport.

- They require a crane or cranes for placement.

- The shape is difficult to adapt to complex geometries such as curved roadway alignments.

- Experience has shown fewer problems with intermediate concrete diaphragms than steel bracing, but the concrete is heavier and requires cast-in-place forming and pouring.

<u>Bulb-Tee Design</u> – Through experience the DOT&PF Bridge Section has developed some design requirements for decked-bulb girders. For prestressing strands, DOT&PF typically uses low-relaxation, 0.5-inch diameter strands, and limits prestressing strand stress prior to transfer to 70% f_{pu}. AASHTO allows 75% of f_{pu} prior to transfer. DOT&PF policy is also to limit tensile stress after losses to zero tension under the Service limit state.

It is DOT&PF practice during design to balance the load ratings for decked bulb-tee girders, i.e. the moment load rating should roughly equal the shear load rating. For example, the moment load rating for decked bulb-tee girders often far exceeds the shear load rating, but the addition of a relatively small number of shear stirrups can balance the load ratings. While unbalanced load ratings can technically meet the requirements for all legal loads, a balanced load rating is a better practice for the long-term capacity of the bridge. Overload permits are common for Alaskan bridges, but the weights and configurations are not similar enough to justify standard overload design cases. Therefore, balanced load ratings allow better capacity for unknown future loads.

With the few exceptions mentioned previously, the design of bulb-tee girders follows *AASHTO LRFD Bridge Design Specifications* and can be easily done by hand or spreadsheet. However, the Bridge Section has developed a program that is useful in designing or checking deck bulb-tee girders. The program is available on the Department's website.

REINFORCED CONCRETE-FILLED STEEL PIPE PILE BENTS. Deep foundations are usually the only practical way to address seismic loading and liquefaction for Alaskan bridges. Further benefits of deep foundations, and specifically the Alaskan concrete-filled pipe pile bent system, is that their installation can be initiated through ice and frozen ground, and can be completed quickly to comply with environmental constraints and short constructions schedules. An even further advantage is that concrete-filled pipe piles, by having a smaller footprint than traditional footings, tend to have reduced scour depths. DOT&PF practice is to add additional pile length to counter anticipated scour, thereby offering long-term scour protection.

This pipe pile bent system is classified by the *AASHTO Guide Specifications for LRFD Seismic Bridge Design* as a Type 1 bridge structural system, because the superstructure is considered essentially elastic and the substructure allows for plastic hinging. When the DOT&PF first began using this substructure system, they embedded the pipe piles in the concrete cap and used a higher longitudinal steel ratio in the column concrete. However, unsure of exactly how this system would perform under seismic conditions, the DOT&PF approached the University of California San Diego (UCSD) to test a full-scale version of the bent system. This testing took place in the 1990s and led to a finding that a few modifications, such as a reduced longitudinal steel ratio and improved cap beam detailing, could be made to the detailing for better seismic performance. With UCSD's assistance in 1998, the current version of Alaska's pipe pile bent was developed and tested. Its significant feature is a "gap" between the top of the steel pile and bottom of the concrete cap. This gap region is actually a continuation of the reinforced concrete core. The concrete gap is designed to have the ductility needed to develop a plastic hinge and therefore acts a fuse in case of seismic loading. The advantage of this hinge location compared to other capacity-protected substructure systems is that the hinge is not buried at the bottom of the pile where it cannot be easily inspected after a seismic event.

Figure 2 – Typical Alaska Bridge with Decked Bulb-tee Girders and Pipe Pile Piers

Seismic Substructure Design – The DOT&PF has adopted displacement-based seismic design which they find more reliable and accurate than force-based design for determining the ductility and strength capacity requirements of a bridge system. Basically, that means that the use of R-factors and an assumed inherent ductile capacity are not sufficiently safe means of designing structures with Alaska's level of seismic activity. Since the *AASHTO Guide Specifications for LRFD Seismic Bridge Design* include performance-based design, the DOT&PF's approach is compatible with AASHTO methods. Furthermore, the design requirements for this type of structure are outlined in the *Guide Specifications*.

Most of DOT&PF's structures fall into Seismic Design Categories (SDCs) B, C, and D. Although pushover analysis is only required by AASHTO for SDC D, since DOT&PF has developed easy ways to do pushover calculations, designers usually run a pushover analysis for multiple-span structures in every SDC.

As with any other materials incorporated in seismic design, control of expected material properties is important for ensuring adequate ductility. For that reason, DOT&PF requires ASTM A706 Grade 60 reinforcing steel instead of ASTM A615 steel. To prevent unintentional substitutions, all reinforcing steel for bridge projects is required to be ASTM A706. To ensure adequate properties in the steel pipe piles, they are required to be manufactured according to American Petroleum Institute (API) 5L PSL2 specifications or fabricated to API 2B specifications, both in an API approved facility.

Past earthquakes worldwide demonstrated that sidewalks and other rigid restraints at the ground level of columns can affect the locations of hinging. This information led the DOT&PF Bridge Section to investigate the influence of frozen ground around their pipe piles. The University of Alaska Anchorage undertook the study of this behavior as a research project in 2011 and made recommendations about the frozen soil properties and relative depth of fixity for deep foundations. As a result of this research, DOT&PF policy is to consider pile bent capacity in both the regular unfrozen soil case and a frozen soil condition. In the frozen soil condition, the depth of fixity moves to approximately 0.5 to 0.75 pile diameters below the ground surface, regardless of the depth of the pile.

Push-over Program – The DOT&PF Bridge Section worked with the University of Oregon to develop an OpenSees program to analyze the lateral load-displacement response of a typical Alaska-style concrete-filled steel pipe pile bent. The software also computes the following helpful information:

- the extreme axial loads in each column,
- magnitude and location of extreme bending moments in each column,
- magnitude and location of extreme shear in each column, and
- moment-curvature and axial-moment interaction of the gap section at the top of the columns and the concrete-filled pipe section.

The user can use the defaults for expected material properties, soil properties, and strain limit states or update these parameters for the specific design situation. Ongoing research sponsored by the DOT&PF Bridge Section will help to better define some of these properties, such as variations in cold temperature properties and enhanced p-y soil curve information.

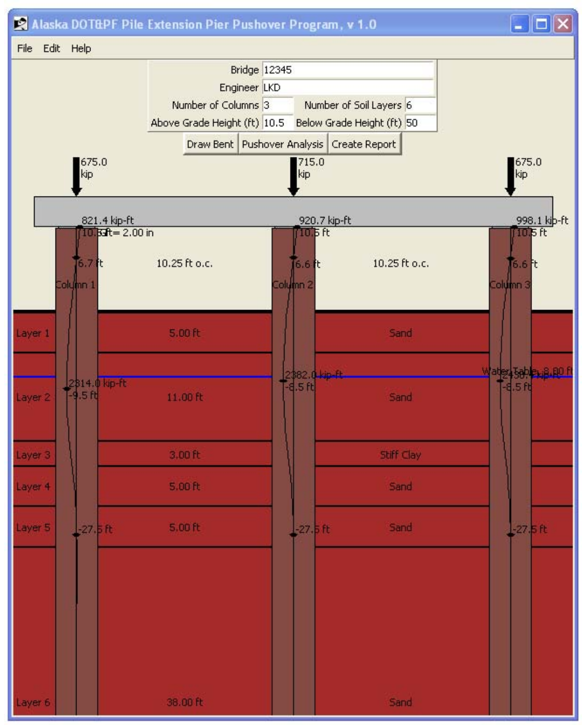

Figure 4 – Pushover Program Input Screen

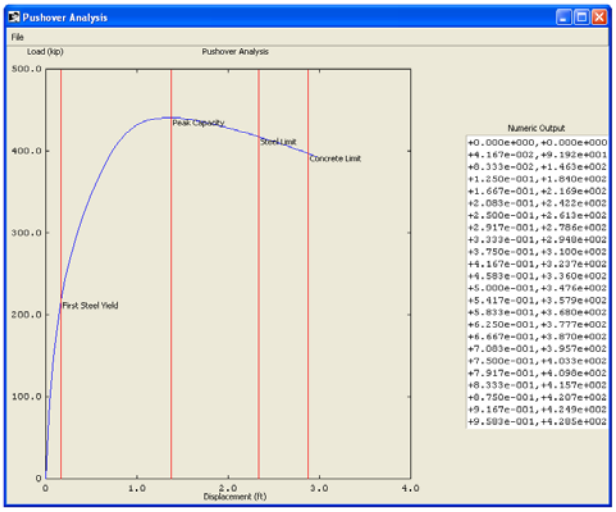

Figure 5 – Pushover Analysis Load-Displacement Curve

RESEARCH EFFORTS – In addition to the previously mentioned research projects by UCSD and UAA, the DOT&PF has retained North Carolina State University (NCSU), Iowa State University (ISU), and the University of Alaska Fairbanks (UAF) for various research studies. Most of the studies focus on the seismic behavior the reinforced concrete bent system, either ductile behavior of the pile system itself or material level behavior of the piles and frozen soil surrounding the piles.

A notable materials testing project in 2008 at NCSU studied the effects of -40°F temperatures on ten large scale circular reinforced concrete columns subjected to cyclic loads. The NCSU study found that the reinforced concrete members exposed to cyclic loading at sub-zero temperatures showed increased strength and some reduced ductility. The practical application from this study was a recommended low temperature hinge length equation, low temperature overstrength factor, and equations for reduced strain values for concrete and steel at low temperatures. However, those recommendations applied only to the temperature tested and had to make certain assumptions based on quantitative methods instead of full-scale system testing. Further studies at ISU and UAA continue to refine the recommendations for frozen materials under seismic loading. Once these studies are finalized, the DOT&PF will be able make standard recommendations for cold temperature seismic cases.

CONCLUSIONS

Bridge engineering in Alaska presents some unusual constraints and challenges compared to other areas of the United States. However, through experience, innovation, and research, the Alaska DOT&PF Bridge Section has been able to engineer practical solutions that meet state-of-the-practice seismic design.

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