Preliminary Study on Application of Population-Based Structural Health Monitoring for Ferry Quays in Norway

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ABSTRACT

Ferry quays are critical components of transportation infrastructure, serving as vital nodes that support the movement of people, goods, and services. This is especially important in coastal regions such as western Norway, where ferry quays provide essential connectivity across wide and deep fjords that are otherwise impassable. Despite their strategic importance, research into the structural performance and health monitoring of ferry quay infrastructure remains limited.

This study explores the potential for applying a Population-Based Structural Health Monitoring (PBSHM) approach to ferry quays in Norway. In contrast to conventional SHM techniques, which typically focus on monitoring individual structures, PBSHM utilizes data from a broader population of similar structures to identify shared patterns, detect anomalies, and improve condition assessment across the network. A fundamental requirement for implementing PBSHM is the ability to evaluate and quantify the structural similarity between assets in the population — a key focus of this research.

Given the number, accessibility, and structural similarity of ferry quays across Norway, this study suggests that PBSHM holds significant promise as a scalable and effective strategy for enhancing the monitoring and maintenance of this critical infrastructure.

INTRODUCTION

The PBSHM idea was created to extend the principles and cover the limitations of traditional SHM approaches that focus primarily on monitoring individual structures in isolation. PBSHM focuses instead on treating different structures as members of the broader population with shared materials, properties, and topology in order to improve health monitoring across the entire population. Such a strategy allows for dealing with problems of data scarcity and, as a result, makes better predictions even when little or no damage data is available for a specific structure.

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A great introduction to PBSHM can be found in the joint work of Bull et al. [1], Gosliga et al. [2], and Gardner et al. [3]. More recently, researchers tried to show that PBSHM can be credibly applied to real-world structures. Notably, two independent studies examined how PBSHM can perform for a population of bridges by comparing similarity metrics and dynamic responses [4-5]. Others focused on providing reliable methods for similarity assessment, for example, by using distance metrics [6] or graph kernels [7].

In this preliminary study, we will examine the applicability of PBSHM for ferry quays in Norway for the first time. The focus of the study is on linkspans (also called ferry dock bridges) – steel bridges connecting ferries with land. The workflow presented in this study begins with the Magerholm linkspan, which is translated into a Finite Element (FE) model, and ultimately refined into an Irreducible Element (IE) model. Then, a quantitative overview of existing linkspans in Møre og Romsdal is given. Finally, Attributed Graphs (AGs) are constructed for two different linkspans, and their structural similarity is qualitatively assessed using the Jaccard similarity coefficient.

LINKSPAN AT MAGERHOLM – CASE STUDY

The BIM model of the Magerholm linkspan is presented in Figure 1. It is still a steel structure consisting of main longitudinal and supporting cross beams suspended on two lifting towers, adjusting its position according to the tidal levels. The front beam is designed to allow for direct connection with a docking ferry, while the fenders behind the main beams help absorb the impact force. More on the Magerholm linkspan can be found in Le at al. [8].

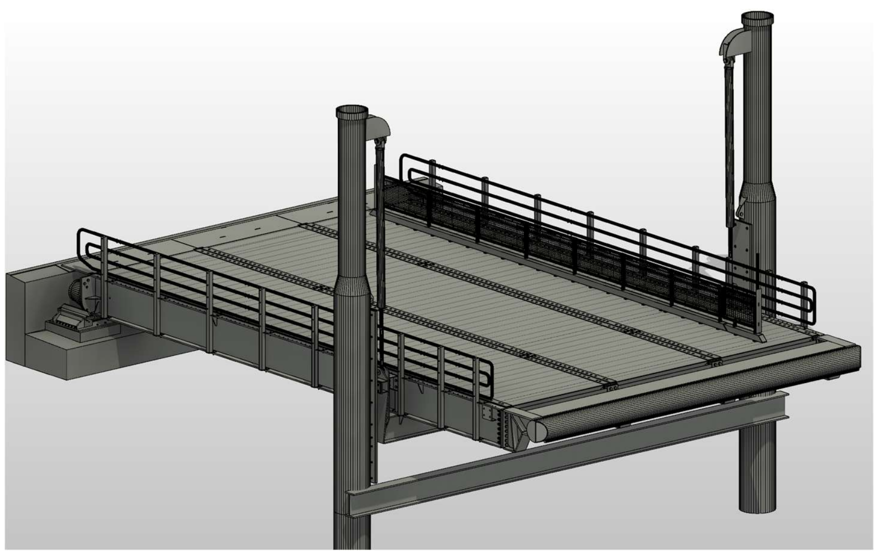

Figure 1. BIM model of the Magerholm linkspan made available by Statens Vegvesen [9].

Based on technical drawings, FE model can be established – see Figure 2. Here, the most important structural elements are easily visible: main and cross beams, front and lifting beams, as well as fenders. Additional balconies that have been later installed on Maherholm were also modelled in the software since they were used as sensor locations in a previous study [8]. The model has already been simplified compared with Figure 1 - nonstructural elements have been replaced with added mass, and the towers have been replaced with vertical springs whose stiffness has been established using finite element model updating [8].

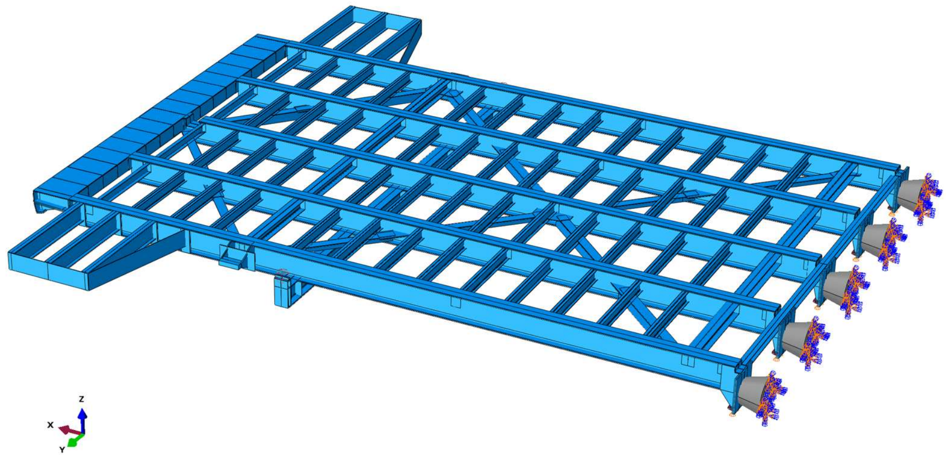

Figure 2. Finite element model of the Magerholm linkspan.

On the basis of Figure 2, the IE representation of the Magergolm linkspan has been created and presented in Figure 3. Here, different nodes indicate different elements, and black lines clearly show how they are connected together. Finally, Table I, inspired by the work of Gosliga et al. [2], presents the properties of different structural elements and supplements the overview of the Magerholm linkspan.

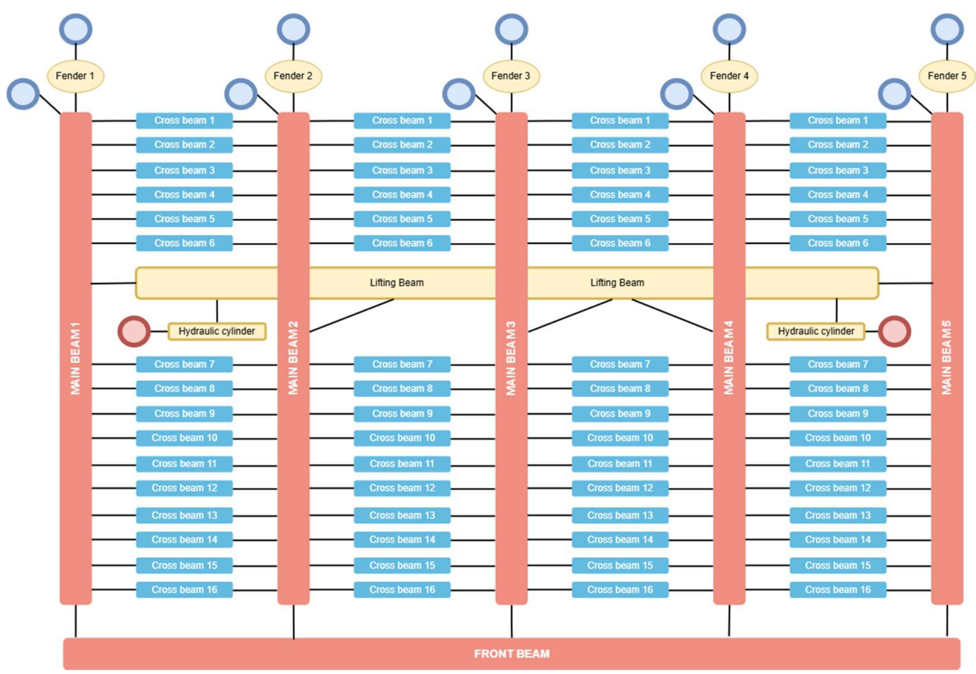

Figure 3. An expanded irreducible element representation of the Magerholm linkspan. Circles represent ground nodes where the boundary condition is defined.

TABLE I. LIST OF ELEMENTS AND THEIR PROPERTIES FOR MAGERHOLM LINKSPAN.

Ferry dock type	Element ID	Material	Geometry	Shape
Main beams	A1-A5	Steel St 52-3	Beam	I - shape
Cross beams	B1-B64	Steel St 37-2	Beam	I - shape
Fenders	C1-C5	Rubber	3D Volumetric	Conical
Hydraulic cylinders	D1-D2	Steel	Beam	Cylinder
Lifting beam	E	Steel St 52-3	Beam	I - shape
Front beam	F	Steel St 37-2/ Hardox	Complex	Rectangular
Abutment	1.1-1.5	Boundary	-	-
Steel roller	2.1-2.5	Boundary	-	-
Lifting tower	3.1-3.2	Boundary	-	-

PBSHM FOR LINKSPANS IN MØRE AND ROMSDAL

In this chapter, we will explore the potential of applying PBSHM to linkspans in Norway by providing an overview of existing linkspans in Møre og Romsdal county. We will also assess the similarity between two selected types of linkspans by presenting their AGs and calculating the Jaccard similarity coefficient.

Population of linkspans in Møre and Romsdal county

Figure 4 illustrates the geographical distribution of linkspans across Møre og Romsdal county, categorized by type. Each colored marker represents a specific linkspan type, helping visualize how the various types are spread throughout the region.

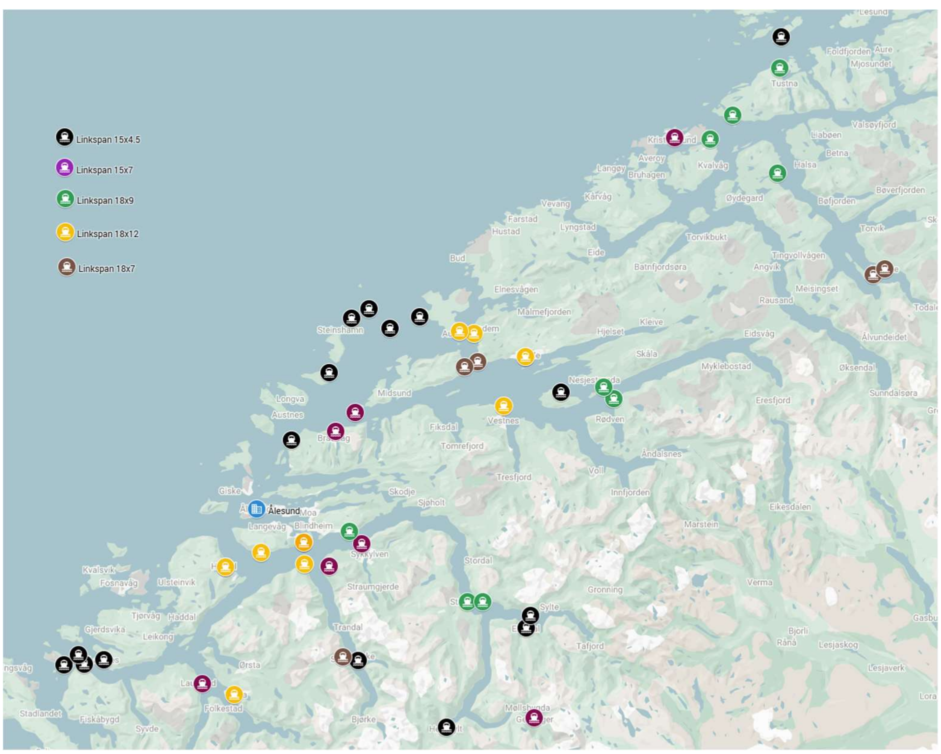

Figure 4. Locations of different types of linkspans in Møre and Romsdal county.

The accompanying Table II summarizes the number of linkspans for each type. It shows that the most common types are the smallest 15×4.5 units, typically used on less busy routes and for connections between coastal islands.

The authors would like to acknowledge that slight differences between linkspans of the same type were observed during field measurements and on-site inspections. For simplicity, these variations are not considered in this study.

TABLE II. AMOUNT OF LINKSPANS OF DIFFERENT TYPES IN MØRE OG ROMSDAL COUNTY.

Linkspan type	**15x4.5**	**15x7**	**18x7**	**18x9**	**18x12**
Number	16	9	5	9	9

Structural similarity

Structural similarity is a key concept in PBSHM, and a convenient measure of how suitable the population of given structures is for applying PBSHM methodologies. High structural similarity across a population of structures will be a strong indicator that knowledge transfer can be applied successfully.

The population of linkspans can be considered to be a heterogeneous population, meaning that the graphs used to represent them are not topologically equivalent [1]. However, due to how linkspans are designed, it is expected that the degree of similarity between different linkspan types will be high (see Table III for element comparison of two different linkspans). In this study, that hypothesis will be examined by calculating the Jaccard similarity coefficients between Magerholm (15x9) and Rykkjem (18x7) linkspans given with the following equation [bridge population based SHM]:

$$J(A,B) = \frac{|A \cap B|}{|A|+|B|-|A \cap B|} \tag{1}$$

Here |A| is 72, equal to the number of elements in linkspan 15x9, |B| is 69, equal to the number of elements in linkspan 18x7, while |A∩B| is 63 and is the number of matching elements or the size of so called maximal common subgraph between two linkspans. Setting numbers in equation (1) yields a Jaccard similarity coefficient equal to 0.81, which can be considered to be very high.

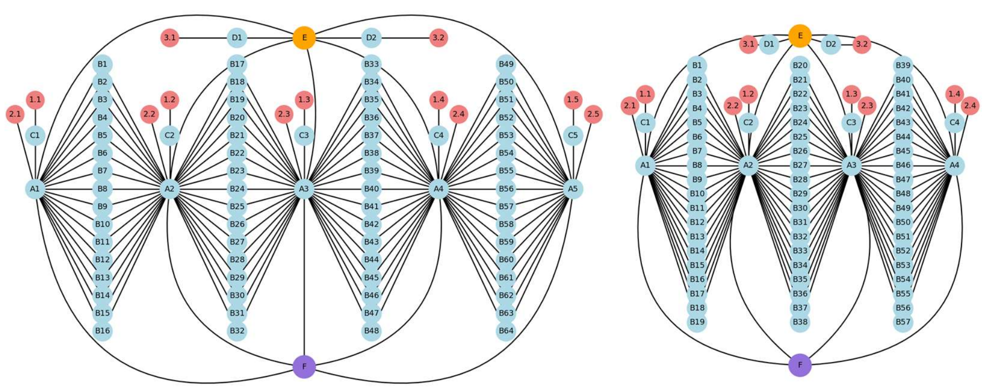

Figure 5. AGs for Magerholm (left) and Rykkjem (right) linkspans.

TABLE III. COMPARISON OF TWO DIFFERENT LINKSPANS USED AT MAGERHOLM (15x9) AND RYKKJEM (18x7) FERRY QUAYS.

Element type	Linkspan 15x9	Linkspan 18x7
Main beams	5	4
Cross beams	16x4=54	19x3=57
Fenders	5	4
Lifting towers	2	2
Lifting beam	1	1
Front beam	1	1

SUMMARY

This study demonstrates the feasibility and relevance of applying Population-Based Structural Health Monitoring (PBSHM) to ferry quay infrastructure in Norway, with a particular focus on linkspans. This research uses the Magerholm case study to introduce an approach to represent linkspans as finite element models through irreducible element models to finally create their attributed graphs. Further, a population of linkspans in Møre og Romsdal county is analyzed, revealing a diversity and amount of different linkspan types as well as a strong presence of smaller units on less-trafficked routes.

Finally, by comparing the attributed graphs of two representative linkspans—Magerholm (15x9 type linkspan) and Rykkjem (18x7 type linkspan)—and computing a Jaccard similarity coefficient of 0.81, the study shows a high degree of structural similarity across the population. These findings support the viability of PBSHM in coastal infrastructure, offering a scalable method to improve condition assessment, maintenance prioritization, and knowledge transfer within heterogeneous asset populations.

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