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Optimization of Accelerometer Sensor Location In Arch Bridge Monitoring System Using The Sensor Elimination Using Capital Assurance Criterion (SEAMAC) Method

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Abstract

In developing countries such as Indonesia, various fields of construction are currently being actively developed, especially bridge construction. Damage to the bridge structure itself requires very large repair costs. Currently, a monitoring system is being introduced to assess the condition of structures against dynamic loads, namely SHMS (Structural Health Monitoring System). The research aims to determine Finite Element Modeling, the optimal location, and several accelerometer sensors. To determine the condition of the arch bridge structure, it is necessary to detect damage through the results of the structural response recorded via the accelerometer sensor. In identifying the optimum number and location of sensors, the method used in this research is SEAMAC (Sensor Elimination Using Modal Assurance Criterion). Where this method is an algorithm method that performs an elimination on the sensor. The optimal placement of accelerometer sensors is determined using the Sensor Elimination Using Modal Assurance Criterion (SEAMAC) method, focusing on the floor plate and the bridge arch frame. Proper sensor placement is crucial as it yields important location data essential for identifying the modal characteristics of the bridge structure. In total, 16 accelerometer sensor locations were identified, with 8 sensors designated for both the floor plate and the arch frame.

Keywords: Optimal Location, SEAMAC Method, Accelerometer Sensor, and Arch Bridge.

INTRODUCTION

Developing countries like Indonesia, especially urban areas, are currently actively developing various construction sectors, especially bridge construction. Bridges act as a link between two separate places such as lakes, rivers, seas, ditches and so on. Whether we realize it or not, infrastructure development is directly related to the safety of users or those around the bridge. If the building being built is not maintained during the specified service life, the durability of the building structure will quickly decrease and the building will quickly become damaged. In addition, structural damage is often hidden so it cannot be seen directly. Based on this situation, health checks and damage detection are necessary to achieve good results [1].

In Islamic University of Riau, which is located in Pekanbaru City, Riau Province, there is an Arch Bridge which serves as the main transportation link to the Faculty of Communication Sciences as it can be seen in Figure 1. The bridge was constructed in 2016 and has been in use for 7 years. The initial design indicated a span length of 16 meters with joint support, but upon re-measurement, the current span length has been found to be 13 meters. It is only one access to the Faculty of Communication Sciences.

Figure 1. The Arch Bridge at the Islamic University of Riau

The bridge is a short-span structure, with a span of less than 40 meters. Originally, the bridge was planned to have pin connections on both sides, but due to ground shifting, the connections became fixed at both ends. The bridge's current measurements are: length 13 meters, width 7 meters, and total height 4 meters.

The bridge floor is made of reinforced concrete with a strength of 21 MPa and a thickness of 0.20 meters. There are 1-meter wide sidewalks on both sides of the bridge, each with a 20 cm thickness. The bridge's arch consists of two curved iron pipes, each with a 20 cm diameter, 17.07 meters in total length, and a pipe thickness of 5.30 cm. The quality of the existing steel pipe is BJ37.

Load factors and environmental conditions such as seismic loads, corrosion, aging factors, and traffic loads affect the life of bridge structures. Changes in these factors can accelerate bridge failure and shorten the service life of the remaining infrastructure. Damage to the bridge structure itself requires huge repair costs. To avoid these losses, it is necessary to assess the bridge's condition based on its dynamic response. A bridge condition assessment is needed to consider the decline in physical performance. Evaluation must be carried out continuously without stopping at the right action. This is a challenge for the construction expert community, especially bridges. With industrial technology in the field of instrumentation and advances in information and communication technology, monitoring the health of bridge structures can be facilitated more easily.

In this study, the SEAMAC (Sensor Elimination Using Modal Assurance Criterion) method was used with the help of the FEMTools program, this program can determine the optimal number and position of accelerometer sensors. Eliminating and detecting which locations give the greatest damage effect, to be able to measure the vibration signal and the most effective control force, so that these parameters become recommendations due to the modal frequency of certain mode shapes analyzed in it. This research aims to determine the optimum location and number of accelerometer sensors on curved bridges using the SEAMAC method.

SHMS (Structural Health Monitoring System) is a new field that is able to detect damage using non-destructive testing methods. This technology can extend the service life of bridges because capacity reduction and damage can be detected early (early warning) before more serious damage occurs, that which requires huge rehabilitation costs [2]. The aim of this SHMS is to detect damage using non-destructive testing methods [6]. By carefully planning the placement of instruments or sensors, this SHMS can collect the necessary data about the condition of the bridge structure such as stress, strain, deflection, temperature, and time-dependent properties such as creep and shrinkage in the structure. This data can also be used to verify assumptions made in the design so that improvements can be made in subsequent bridge designs, assess the general condition of bridges, and provide data for the infrastructure management system in making decisions [6].

In accordance with the concept of the purpose of installation, there are several choices of monitoring levels. The level depends on the parameters to be monitored. Structural Health Monitoring System (SHMS) levels are classified into 4 classes, namely [7] :

1. Class 1 with essential requirements for all bridge types.
2. Class 2 with necessary requirements for Optimal Structural Health Monitoring System.
3. Class 3 with the need for minimal maintenance.
4. Class 4 with good to know needs.

Based on this classification, levels or levels of SHMS are made which are then divided into 3 levels or levels, namely [7]:

1. Basic level is a combination of class 1 and class 2.
2. Intermediate level is a combination of class 1, class 2, and class 3, and
3. Advance level is the entirety of class 1 through class 4.

Therefore, related to the 3 parts of sensors and equipment above, the sensors and equipment in SHMS used in this study are the second, where the sensors and equipment in SHMS used are sensors related to the response of bridge structures using accelerometer sensors [8].

G-Link 200 Accelerometer

The G-Link 200 accelerometer is a type of onboard tri-axial accelerometer sensor designed for high-resolution data acquisition with minimal noise and drift. With controlled vibration parameters, it enables long-term monitoring of key performance indicators while maximizing battery life. The wireless sensor network from LORD Experience allows for simultaneous and rapid data acquisition and integration from a scalable range of sensors.

The wireless detection system is ideal for various applications, including testing and measurement, remote monitoring, system performance analysis, and embedded systems. Programming nodes for burst, continuous, periodic, or event-triggered sampling is made simple using our sensor integration software. Additionally, our optimized web-based cloud sensor application enhances data aggregation, analysis, and integration for embedded applications. Bridges typically experience vibrations when loads or vehicles pass over them. The accelerometer can detect vibrations along the X-axis, Y-axis, and Z-axis (three axes).

The shape of the G-Link 200 wireless accelerometer is illustrated in Figure 2 below:

Figure 2. The G-Link 200 Accelerometer

Finite Element Modelling by Using Software FEMTools V.4.3

Computer simulation modeling using finite element analysis is a numerical method used to predict the behavior of physical systems or structures by breaking them down into discrete elements and analyzing the interactions between these elements. This process employs finite element modeling programs.

Finite element modeling plays a crucial role in pre-test analysis since it can forecast how a structure or system will perform under certain loading conditions. This ensures that physical testing is conducted effectively and efficiently. By creating an initial model of the structure, we can simulate its behavior under various loading conditions and predict its response to those loads. This modeling also helps identify areas or components that may be prone to damage or failure during physical testing.

Finite Element Modeling (FEM) is performed prior to pre-test analysis, and there are several significant advantages to this approach:

1. Structural Response Prediction.
   FEM allows for the modeling and analysis of structural behavior before physical pre-tests are conducted. It enables the prediction of structural responses such as deformation, stress, and displacement under various loading conditions. This detailed understanding of the structure's behavior aids in predicting how it will respond during pre-test analysis.
2. Design Optimization.
   FEM facilitates the evaluation and optimization of designs before conducting pre-test analysis. It allows for the testing of various design configurations, materials, and dimensions to identify the optimal design, saving time, money, and resources. FEM enables quicker and more efficient iterative simulations and the testing of design alternatives.
3. Identification of Potential Problems.
   Through FEM, potential design flaws can be identified before physical pre-test analyses. It helps pinpoint critical points, inadequate stiffness, or load imbalances affecting a structure's performance. Understanding these issues beforehand allows for necessary adjustments to the design or experimental setup.
4. Time and Cost Savings.
   Conducting pre-test analysis can be an expensive, complex, and time-consuming process. By utilizing FEM upfront, the number of physical experiments required can be reduced, resulting in significant savings in time and costs associated with testing.
5. Estimation of Error Limits.
   In some instances, FEM can estimate the failure limits of a structure before pre-test analysis is performed. By conducting preliminary modeling and analysis, people can determine if the structure meets strength and safety requirements, or if it is at risk of significant damage. This allows for appropriate precautions to be taken before the physical testing.

Thus, by conducting FEM analysis before pre-test analysis, we can optimize the initial structural design by predicting structural responses, identifying potential problems, and achieving cost and time savings. This ensures that the implementation of FEM prior to pre-test analysis is both effective and efficient. In this study, the initial structural modeling (FEM) was conducted using the SAP2000 V14.2.2 program. The modeling results obtained with SAP 2000 were then exported to the FEMtools program for analysis and calculation of sensor positions, aiming to determine the optimal position for accelerometer sensors on the bridge structure.

Analysis of Pre-Test Accelerometer Sensor Location Optimization

Pre-test analysis refers to the process of analysis conducted before physical testing or experiments take place. This process involves numerical modeling of the structure or system being tested and uses numerical analysis to predict how the system will respond to various loading and environmental conditions.

The primary goal of pre-test analysis is to reduce the amount of physical testing needed and to optimize test outcomes. By employing pre-test analysis, it becomes possible to forecast how the system will behave under specific loading conditions. This approach allows designers to refine the structure or system before any physical testing is executed.

Conducting pre-test analysis helps to minimize measurement errors and ensures that the results accurately reflect the actual vibration conditions. When using Finite Element Method

(FEM) analysis, various parameters can be optimized to achieve the best possible results, including:

1. The location of the excitation points on the bridge structure.
2. The placement of suspensions and boundary conditions that yield good mode shape independence results.
3. The collection of Degrees of Freedom (DOF) responses to be measured.
4. The positioning of sensors.

Data Acquisition Parameters in Bridge Monitoring

In conducting this monitoring there are several important parameters that need to be considered. The following describes some important parameters that are usually needed for most in a bridge monitoring test and implementation [9].

1. Number of Sensors, In any testing or monitoring application, the number of sensors will depend on the size and complexity of the structure and on the complexity of the behavior being evaluated. This is not uncommon n for large-scale testing and *monitoring applications and even some medium-sized bridges that utilize 120 or more sensors.* The performance characteristics of data acquisition hardware often depend on the number of sensor channels being scanned.
2. Sensor Type: The types of sensors that will be used will determine many of the required characteristics of the data acquisition hardware. For example, a resistance strain gauge has specific *output requirements* and signal conditioning characteristics. Data acquisition will usually vary for each type of sensor used. Furthermore, in most applications more than one type of sensor will be required. It is important to ensure that the data acquisition hardware characteristics match the requirements for each sensor type so that the most accurate and reliable measurements can be obtained.

Shape Mode Analysis on Optimizing the Location of Accelerometer Sensor Points

Shape analysis mode can be used to determine the optimum location of the accelerometer sensor in a structure or system. Shape Mode Analysis makes it possible to determine the vibration modes in a structure to be analyzed, so that it can help in determining the optimal location to place the accelerometer sensor. In Mode Shape analysis, the structure or system is modeled as a mass-spring system expressed in the form of a complex numerical equation. Then, these equations are solved and the eigenvalues and eigenvectors are obtained. The eigenvalue represents the frequency and shape of the vibration modes of a structure or system, while the eigenvector represents the vibration pattern that occurs in each mode.

By using the results of the Mode Shape analysis, it is possible to identify possible locations for placing the accelerometer sensor in each identified vibration mode. The appropriate location can be selected based on the vibration pattern in each mode, thus ensuring that the accelerometer sensor is placed in a location capable of detecting vibrations optimally. In determining the optimum location for the accelerometer sensor, Shape Mode analysis can help speed up and facilitate the process of selecting the right and accurate location. By paying attention to the resulting eigenvalues and eigenvectors, as well as considering factors such as critical load locations, nodal points with maximum vibration amplitudes, and the response of the structure or system as a whole, optimal accelerometer sensor locations can be selected and ensure accurate and reliable analysis results.

Mode Shape is the vibration pattern of a structure when influenced by a certain force or condition. The types of Shape Modes can vary depending on the shape, size and material of the structure. Some common types of shape modes that can be found in structures are as follows:

1. Shape Bending Mode: This shape mode occurs when the structure experiences a bending or bending force . The vibration shape is similar to the sinusoidal wave pattern on the surface of the structure.
2. Torsional Shape Mode: This shape mode occurs when the structure experiences torsion or rotational forces . The vibration shape is similar to the circular pattern on the surface of the structure.
3. Shape Shear Mode: This shape mode occurs when the structure experiences a shear force. The vibration shape is similar to the diagonal pattern on the surface of the structure.
4. Combined Shape Mode , This Shape Mode is a combination of one shape mode with another, and occurs when the structure experiences complex forces or a combination of several forces.

In this research will be evaluated on an arch bridge, where this bridge is an access to the Faculty of Communication Sciences on the campus of Riau Islamic University. This steel arch bridge is a type of bridge whose frame forms an arch and is then tied to a hanger or steel cable to distribute the bridge floor load to the bridge abutment[3][4][5]. On this bridge will be carried out, identification of the number and location of sensors in monitoring the bridge that must be planned properly. In this study, the SEAMAC (Sensor Elimination Using Modal Assurance Criterion) method was used with the help of the FEMTools program, this program is able to determine the optimal number and position of accelerometer sensors. Eliminating and detecting which location gives the greatest damage effect, so as to measure the most effective vibration signal and control force, so that these parameters become recommendations due to the modal frequency of certain mode shapes analyzed in it.

METHOD

Structural Health Monitoring System (SHMS) is a building structural health monitoring system that uses a technological base consisting of various types of sensors so that it can provide real data from the elements of a building. The following are the stages of installing SHMS on the bridge structure:

1. Installation can be carried out on the lower structure and upper structure of the bridge.
2. After the sensor installation area has been marked, installation for sensor installation and mounting can be carried out in the field with a design that adapts to the shape of the sensor.
3. The data logger and interface module will be placed in the panel box according to the number of components to be assembled.
4. After the sensor is installed, the sensor data cable is installed using a conduit pipe (outbow installation) to make repairs easier.
5. The positioning of the control panel will be adjusted to conditions in the field with IP Standards.
6. Checking the signal and function of each tool.
7. Testing and commissioning tests to ensure data can be sent.

Optimum Location Determination Methodology

Methodology for determining the optimum location using pre-test analysis used in testing or experiments. The method for determining the optimum location is more related to selecting the most optimal physical or geographic location which is used in placing the optimum location of sensor points in measuring vibrations of a structure in the field. In determining the optimum sensor location, there are four methods that can be used, namely:

1. Modal assurance criterion (MAC)

Modal assurance criterion (MAC) is a method that is often used for quantitative comparison of capital vectors. The modal assurance criterion (MAC) is formulated as a scalar product of two sets of vectors {φA} and {φX}. The scalar results will be compiled into the Modal Assurance Criterion (MAC) matrix [10].

$$MAC(r,q) = \frac{\left| \{\varphi_A\}_r^T \{\varphi_x\}_q \right|^2}{\left(\{\varphi_A\}_r^T \{\varphi_A\}_r \{\varphi_x\}_q^T \{\varphi_x\}_q \right)} \quad (1)$$

After that, the coherent function form will be obtained and indicate the relationship between $\{\varphi_A\}$ and $\{\varphi_X\}$. Meanwhile, the Modal assurance criterion (MAC) which is often used as a constant correlation modeshape which measures the accuracy of identical modeshapes in complex vibrational modes is

$$MAC(r,q) = \frac{\left| \{\psi_A\}_r^T \{\psi_x\}_q^* \right|^2}{\left(\{\psi_A\}_r^T \{\psi_A\}_r^* \right)\left(\{\psi_x\}_q^T \{\psi_x\}_q^* \right)} \quad (2)$$

Where:

{ φA} r : Compatible Analytical Modal Vector, R Mode
{ φX }q : Test Modal Vector, Q Mode
{ ψA}ri : Eigenvector Defined The Complex Damped Mode Of Vibration
{ ψx}q : Eigenvector Defined The Complex Damped Mode Of Vibration

2. Iterative Guyan Reduction

Guyan reduction repetition is an optimal sensor placement method that checks the ratio of diagonal mass to diagonal stiffness repeatedly until the desired modal size and accuracy are achieved. Guyan reduction can effectively reduce the system capital if the lowest mode of the system includes the target capital matrix. The DOF that is the stiffest and has the smallest inertia will be eliminated. After that, the ratio of the diagonal elements of the stiffness and mass matrices calculates the level of importance of each DOF. A low ratio indicates the DOF has significant inertia, while a higher ratio indicates the DOF has significant stiffness [11]. For the formulation, first all FE masses and their stiffnesses will be reduced to become DOF candidates. The mass stiffness ratio is then calculated as follows:

$$R_i = \frac{K_{G_{ii}}}{M_{G_{ii}}} \quad (3)$$

Where:

R_i : mass stiffness ratio
K_G : Stiffness Matrix
M_G : Guyan Reduction Mass

KG and MG are the stiffness and mass reduction matrices of Guyan. DOF which has a value of Ri The biggest will be eliminated. The DOF selection process will repeat continuously until only the desired DOF Ns remain.

3. Effective Independence (EI)

The aim of the Effective Independence (EI) method is to obtain the measurement position that makes the desired mode shape linear as independently as possible while obtaining information about the target modal response in the calculation [12]. The Effective Independence (EI) method comes from estimation theory with sensitivity analysis of the parameters to be estimated, then comes to maximizing Fisher's information matrix, for example the determinant or trace, and minimizing the value conditions of the information matrix. The number of sensors will be reduced by removing sensors from the DOF that have the least contribution among all candidate sensors for linear independence of the target mode. So that the remaining sensors used in the measurement will become the optimal sensor set.

4. Capital Kinetic Energy (MKE)

The Modal Kinetic Energy (MKE) method is a calculation of the dynamic contribution of each candidate sensor to the target mode shape [13]. With Modal Kinetic Energy (MKE) we will get information about DOF which has dynamic features that are relevant to the structure, besides that Modal Kinetic Energy (MKE) also helps to choose sensor positions that have large amplitudes and reduce the noise to signal ratio. To calculate the rank value of all sensor position candidates based on their Modal Kinetic Energy (MKE) is as follows:

$$MKE_{pq} = \emptyset_{pq} \sum_{s=1}^{n} M_{ps} \emptyset_{sq} \tag{4}$$

Where:

MKE $_{pq}$: Kinetic Energy p th

ϕ $_{pq}$: p th component

qth : Shape mode

MKE_{pq} is the kinetic energy associated with the p th DOF in the q th mode target, $\phi_{pq}$is the p th component corresponding to the q th mode shape. The sensor location with the highest MKE value will be selected as the measurement sensor set. So the methodology for determining the optimum location of accelerometer sensor points in this final research project is the Sensor Elimination Using Modal Assurance Criterion (SEAMAC) method. This method is a technique for reducing the number of sensors used in measuring the vibration of a structure. The aim is to optimize the performance of the measurement system and analyze the relationship between the vibrations of a structure and the vibration sources that cause them. The Sensor Elimination Using Modal Assurance Criterion (SEAMAC) method uses the Modal Assurance Criterion (MAC) to select sensors that can be removed from the measurement system. Modal Assurance Criterion (MAC) is used to measure the similarity of modes between two structures or two different modes of a structure. In the Sensor Elimination Using Modal Assurance Criterion (SEAMAC) method, the Modal Assurance Criterion (MAC) is used to compare the vibration modes in the measured structure with the modes produced by the numerical model of the desired structure [14].

The Modal Assurance Criterion (MAC) will lay the foundations of the SEAMAC algorithm, which tests the removal of each DOF candidate sensor and performs one that produces the minimum largest off-diagonal term of the MAC Matrix. This process is then repeated for the remaining candidate sensor DOFs. Clearly, although this procedure is a major step forward towards an automated process, review from an experienced engineer is necessary and important to ensure valid sensor settings.

By using the Modal Assurance Criterion (MAC), sensors that are less important in vibration measurements can be identified and eliminated. The SEAMAC method can increase the accuracy of measurement results and reduce measurement costs because it reduces the number of sensors used in measurements. However, keep in mind that sensor removal should be done carefully and based on a good understanding of the structure being measured and the vibration sources involved.

Through the Sensor Elimination Using Modal Assurance Criterion (SEAMAC) method in the FEMtools program, vibration measurements can be optimized by reducing the number of sensors used and increasing the accuracy of measurement results. Apart from that, FEMtools also provides other analysis features and modules that can be used to deepen the analysis of vibration and structural dynamics.

After final review, the Auto-MAC matrix of the reduced test model can be seen in Figure 3. It is shown that the off-diagonal term assumes quite small values, given the observability of the modes and their linear independence.

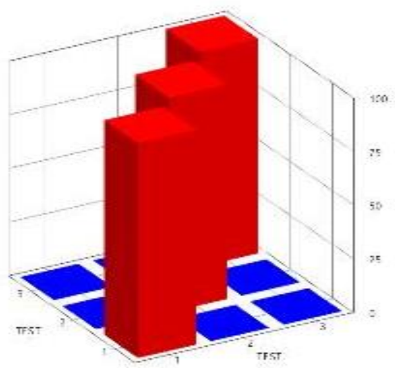

Figure 3. Auto-MAC matrix for the test model (all DOFs vs test DOFs) (FEMTools Software)

Based on the image above, there is an image like a chart in the AutoMac Test menu, this is a functional correlation, which means there is a correlation between mode 1 and the other modes to determine the final result. This method tries to find a measurement point configuration that minimizes the Modal Assurance Criterion (MAC) value in off-diagonal terms. The Sensor Elimination Using Modal Assurance Criterion (SEAMAC) method is based on repeatedly eliminating one by one the degrees of freedom that show a lower impact on the Modal Assurance Criterion (MAC) value. This iterative process stops when the default Capital Assurance Criterion (MAC) matrix is reached, high values in diagonal terms and low values in off-diagonal terms [15].

RESULTS AND DISCUSSION

The FEMTools program recommends using 36 sensor points, based on an initial random sensor location. However, this recommendation may not align with the sensors currently available. Despite this limitation, it is still possible to optimize our sensor selection. We can utilize the Sensor Selection Menu in the FEMTools program and adjust the number of sensors to reflect our specific needs, which is 16 optimum sensor points.

At this time, the Sensor Elimination Method Using Modal Assurance Criterion (SEAMAC) will carry out sensor elimination where the SEAMAC method will try to find a measurement point configuration that minimizes the MAC value in off-diagonal terms. The SEAMAC method is also based on repeatedly eliminating one by one the degrees of freedom that show a lower impact on the Capital Assurance Criterion (MAC) value. This process will repeat until it stops when the default MAC matrix has reached, high values in diagonal terms and low values in off-diagonal terms. For more details, the design of the location of the accelerometer sensor based on the sensor selection number of sensors on the curved bridge model can be seen in the Figure 4.

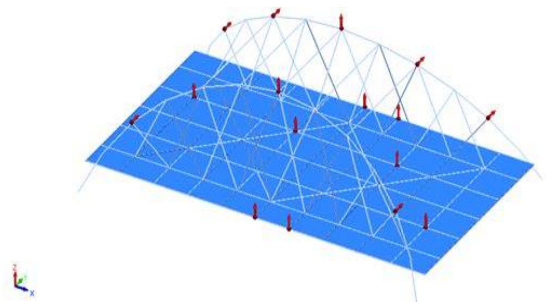

Figure 4. Accelerometer Sensor Location Design based on Sensor Selection Number of Sensors on a curved bridge model

After the final review, the Auto -MAC matrix of the reduced test model can be seen in Figure 3 where the image is like a chart in the AutoMac Test menu, this is a functional correlation, which means there is a correlation between mode 1 and the other modes to determine the final result.

So, the AutoMAC Test diagram below is a way to carry out analytics and experiments according to the frequency and shape modes that we determine. The meaning of Test 1-12 in the AutoMAC Test diagram is that we carry out analytics and experiments according to the frequency and shape modes that we determined at the beginning. Modal Assurance Criterion (MAC) is a statistical indicator that is most sensitive to changes in the mode shape (vibration range) of the structure. MAC is often used to relate analytically derived modes to experimentally derived modes. The closer the MAC is to 100%, the more consistent the model shows. So the results of the curved bridge Auto-MAC matrix can be seen in Figure 5.

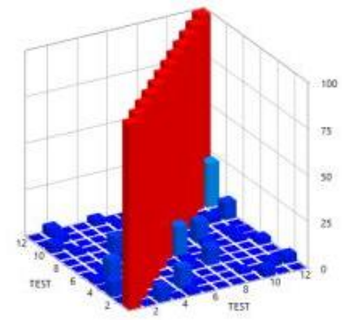

Figure 5. Auto -MAC matrix for the test model

From the results of the pre-test analysis and direct observations in the field on the curved bridge, the type of sensor, number of sensors and optimum sensor placement position for the SHMS curved bridge were obtained. So the results of the analysis of sensor requirements on SHMS arch bridges in the field can be seen in Table 1.

Table 1. Results of analysis of sensor requirements on arch bridge SHMS

No	Sensor Type	Sensor Function	Number of Sensors (Piece)	Placement Position
1.	Accelerometer G-Link 200	Measuring the natural frequency and modal shape of the bridge	8	Floor Plates
2.	Accelerometer G-Link 200	Measuring the natural frequency and modal shape of the bridge	8	Curved Truss

3-Axis accelorometers that will be installed, placed on 8 bridge floor plates and 8 on the frame arches. The accelerometer sensor is used during bridge service. Accelerometers are useful for measuring natural frequencies and modal shapes on bridges. The 3-Axis accelerometer on the arch frame is used to check stress from frequency while on the floor plate to provide an overview of the vibrations that occur.

Based on the accelerometer sensor location design that has been recommended by FEMTools in the Sensor Selection menu and determining the number according to the number of requirements in the Candidate Sensor Locations on the bridge model, the sensor placement is determined on the floor plate and arch frame of the bridge, so the total number of accelerometer sensor location points as a whole is namely 16 points where there are 8 accelerometer sensor location points on the floor plate and 8 sensor location points on the bridge arch frame.

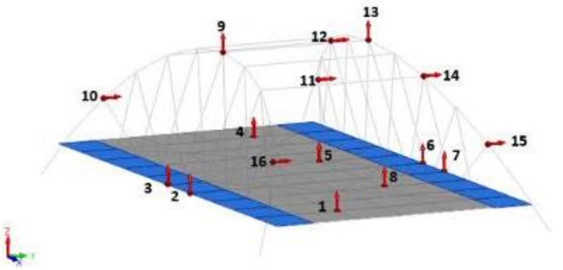

Figure 6. Accelerometer Sensor Location Design based on existing conditions

Based on the direction indicator for placing the accelerometer sensor above, the accelerometer sensor has three axes: X, Y, and Z axes. The X axis refers to horizontal movement to the left and right, the Y axis refers to horizontal movement forward and backward, and the Z axis refers to vertical movement. up and down. Based on the image above, there are only two indicators for the direction of the accelerometer sensor, namely the Y and Z directions.

On the floor plate there is only one indicator of the direction of the accelerometer sensor, namely the Z direction . The largest force received on the floor plate is also located in the z direction. This is also proven based on the modeling results that the largest moment is found on the floor plate. Meanwhile, in the frame there are two directions, namely the y and z directions, where the Y direction sensor indicators are at points 10, 11, 12, 14, 15, and 16 and the Z direction indicators are at the middle of the arch span. This is because in the Y direction there are forces acting due to compressive and suction wind loads. Meanwhile, the Z indicator is located in the middle of the frame span because at that point there is the largest moment force received by the arch.

CONCLUSIONS

Using the Finite Element Analysis (FEA) program, we obtained the mode shapes for 12 FEA. These mode shapes include treatments for longitudinal bending, transverse bending, and overall torsion. Consequently, a comprehensive FEA was conducted to identify the optimal locations and the number of accelerometer sensors needed for the arch bridge. The optimal placement of accelerometer sensors is determined using the Sensor Elimination Using Modal Assurance Criterion (SEAMAC) method, focusing on the floor plate and the bridge arch frame. Proper sensor placement is crucial as it yields important location data essential for identifying the modal characteristics of the bridge structure. In total, 16 accelerometer sensor locations were identified, with 8 sensors designated for both the floor plate and the arch frame.

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