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DYNAMIC BEHAVIOURS REVIEW OF THE JETTY STRUCTURE TO BE DECLARED AS BUILDING FUNCTIONAL SUITABILITY

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Abstract

The building structure must be in a state of excellent repair and adhere to technical feasibility standards in terms of safety, comfort, and compliance with regulations in order to effectively fulfillfulfil its intended purpose. Structural performance may be assessed by measuring deflections in beams, seeing fractures in slabs, and detecting vibrations that disrupt the comfort of building occupants. The standard SNI 2847 2019 mandates the permissible deflection for concrete slabs and beams. The Decree of the Minister of Environment No.49 of 1996 and ISO 2631-2 1989 mandate that vibrations must not cause harm to structures or disrupt human comfort and well-being. The vibrations experienced at the jetty due to walking and wave loads are currently within acceptable limits. However, an assessment of the jetty's dynamic parameters, such as natural frequency and damping, indicates that it is in a state of significant structural damage. The damage level is estimated to be between 38.53% and 60.73%, resulting in a decrease in its capacity by 58.04%. This study demonstrates that the dynamic parameters have been validated as capable of accurately estimating the extent of structural damage to structures. Through eye inspection and a series of tests, the jetty's many flaws may be dynamically studied and evaluated using various factors. The findings obtained from the dynamic parameter analysis, namely the frequency, elastic modulus, and damping, accurately indicate the extent of damage that closely corresponds to the real item. According to this, it may be guaranteed that the frequency is precise and trustworthy. Upon visual inspection of the building, no issues are apparent. However, during the field dynamic test, an unusual frequency is detected and there is a significant amount of damping. A high damping measurement indicates a significant dissipation of energy in the structure. Significant damping reveals the precise location of fractures during vibration.

Keywords:

Jetty;
Dynamic;
Strength;
Vibration;
Function.

1 Background

In the realm of construction, several instances of building structure failures occur as a result of various circumstances, including the disregard of planners, contractors, supervisors, and even owners. This phenomenon may be attributed to a multitude of circumstances, spanning from insufficient financial resources to deliberate efforts aimed at compromising the standard of construction, driven by specific goals. There are several methods available to assess the building's functional suitability and ensure it remains classified as a building. Building evaluations are evaluated by many methods, including the re-measurement of building dimensions and slopes, material testing, and both destructive and non-destructive tests.

Physical testing in structural engineering encompasses three types: monotonic, cyclic, and dynamic. Monotonic testing refers to the process of subjecting a material to tension or compression testing while gradually increasing the applied load. For instance, a steel tensile test involves subjecting a steel bar to tension, which yields information on the Young's modulus, yield stress, and ultimate stress of the steel. Cyclic tests subject the specimen to multiple cycles of tension and compression. Cyclic

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tests are conducted at modest loading rates, known as quasi-static, and provide significant insights into the fatigue performance and energy dissipation capability of the material or structural component being studied. Crucially, cyclic experiments may be readily replicated. Dynamic testing simulates dynamic loading situations, such as free vibration, impact, earthquake, or wind loading, by using test facilities with different levels of complexity [1].

With the advancement of computer calculating tools in the area of structural engineering, it may seem unnecessary to conduct physical tests on building structures. Dynamic testing of building structures is essential for verifying design ideas and calibrating analytical models, particularly for buildings exposed to earthquakes and assessing occupant comfort. Dynamic parameters have shown their ability to forecast the magnitude of structural damage to structures. Understanding the physical aspects of engineering performance is necessary in the creation of innovative damping devices. After doing the physical performance assessment, it may be further simulated using numerical models to explore other applications. Structural engineering practice seldom involves such testing, yet it continues to be a crucial aspect of the advancement of structural engineering knowledge. The necessity of testing is apparent from previous engineering mishaps, such as the 1940 collapse of the Tacoma Narrows Bridge in Washington, USA, caused by inadequately comprehended wind-induced vibrations, or the 1995 Kobe earthquake in Japan, which revealed flaws in the design of steel moment-resisting truss connections [1].

Dynamic tests have been used from the late 19th century till the present to analyze and characterize the fundamental theory of vibration for trusses, beams, plates, and shells. Recently, there has been significant progress in developing a comprehensive knowledge of the dynamic behaviorbehaviours of intricate building structures or components. These structures or components are scaled down and subjected to cyclic testing and shaking tables. The rules have provided a definition for cyclic testing, which serves the purpose of facilitating easy and documented retesting [1]. The building must be in a sound state and adhere to technical feasibility standards in terms of safety, comfort, and compliance with regulations in order to effectively fulfill its intended purpose.

The regulatory standards establish the permissible limits of deflection for concrete slabs and beams. They also include vibration restrictions that must not disrupt comfort, pose a risk to human health, or result in any damage to the structure [2]. The study aimed to assess compliance with deflection limits on concrete slabs and beams according to SNI 2847-2019 [3], and vibration requirements according to the Decree of the Minister of Environment No.49 of 1996 [2] and ISO 2631-2 1989 [4]. In addition to determining the level of safety, comfort, and technical feasibility of the jetty, this study also aims to provide reinforcement recommendations to improve jetty performance and reduce perceived vibrations.

2 Standardised Vibration Levels

Although the standards for validating ultimate limit states and calculating design code deflections are sufficient, there are still certain uncertainties in the computation and evaluation of floor vibration during the design stage. The uncertainties are associated with: (a) selecting suitable design models that consider the impact of frequency, damping, displacement amplitude, velocity, and acceleration to accurately predict the dynamic response of the floor structure during the design phase, (b) defining the boundary conditions for the model, (c) determining the form and intensity of the excitation, and (d) evaluating the floor response based on the intended use and user satisfaction [5].

It is important to inspect the slab and beams that support it to verify that any vibrations induced by operations above do not impact the functionality of the structure. If there is a potential for the building to experience vibrations, it is necessary to implement precautions to avoid discomfort, feelings of insecurity, structural damage, or disruption to its intended purpose [5]. The mechanical vibration and shock vibration level standard refers to the highest permissible level of mechanical vibration resulting from commercial or operational operations in dense environments, in order to prevent any disruption to comfort, health, and structural integrity of the structure [2].

Table 1: Vibration Level Standards for Comfort and Health [2]

Freq. (Hz)	Vibration Level Value, in microns(10^6)			
	Still allowed	Disturbing	Uncomfortable	Painful
4	< 100	100 – 500	500 – 1000	> 1000
5	< 80	80 – 350	350 – 1000	> 1000
6,3	< 70	70 – 275	275 – 1000	> 1000
8	< 50	50 – 160	160 – 500	> 500
10	< 37	37 – 120	120 – 300	> 300
12,5	< 32	32 – 90	90 – 220	> 220
16	< 25	25 – 60	60 – 120	> 120
20	< 20	20 – 40	40 – 85	> 85
25	< 7	7 – 30	30 – 50	> 50
31,5	< 2	2 – 20	20 – 30	> 30
40	< 9	9 – 15	15 – 20	> 20
50	< 8	8 – 12	12 – 15	> 15
63	< 6	6 – 9	9 – 12	> 12

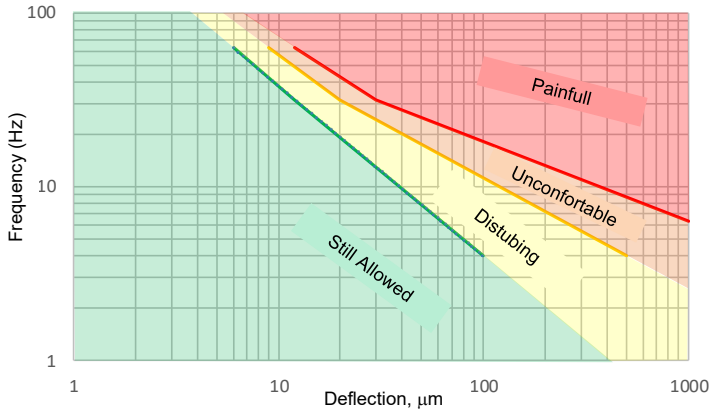

Fig. 1: Mechanical Vibration Level Standards for comfort and health [2]

3 Dynamic Floor Response

The behavior of the floor structure in reaction to the activities occurring above it is governed by the loading characteristics, as well as the structural dynamics and qualities of the floor. The floor response is influenced by the dynamic characteristics of the floor structure, which include the eigen frequency (fi), modal mass (Mmod,i), and damping value (Di) for each vibration mode (i). The different modes are often categorized based on their energy content. The initial mode (i = 1) necessitates the minimal energy content for excitation. Resonance occurs when the eigen frequency of a mode matches the frequency of the movement above it, resulting in a significant increase in response amplitude [6].

Resonance may also manifest in higher modes, meaning when multiples of the movement's frequency align with the frequency of the floor. The response amplitude of the floor structure is often constrained by the following factors: The weight of the floor structure. The number of impulses of the above movement is limited by the floor's dimensions, specifically the ratio of the overhead movement's mass to the mass of the floor it is interacting with. This ratio will impact the vibration. Additionally, the damping factor D, which dissipates the excitation energy, will also play a role. The damping of a structure, known as Damping Di, is comprised of three components: D1, which is caused by internal friction inside the floor or at the connections to other structural components; D2, which is caused by equipment; and D3, which is caused by permanent installations and finishes [5].

Damping refers to the process of dissipating energy in a vibrating system. The components of total damping include: (a) material and structural damping, (b) damping resulting from finishing, and (c) geometric radiation (the transmission of energy through the structure). Often, a system consisting of n

degrees of freedom may be simplified to a n single degree of freedom (SDOF) system with a certain frequency:

$$f_i = \frac{1}{2\pi}\sqrt{\frac{K_{mod,i}}{M_{mod,i}}} \quad (1)$$

The above equation represents the relationship between the natural frequency (fi), modal stiffness (Kmod,i), and modal mass (Mmod,i) of the i-th system. The modal mass refers to the mass that is specifically engaged or involved in a certain mode.

Each mode of the structure has distinct dynamics that are associated with the geometry of the vibration mode and the time T [s] of a single oscillation. The frequency, denoted as f, is the reciprocal of the oscillation period, represented as T (f = 1/T). The natural frequency refers to the inherent frequency of oscillation that diminishes with time without being constantly stimulated by an external excitation source. Each structure has an inherent frequency and corresponding mode forms as degrees of freedom. Typically, they are arranged based on the level of energy generated by oscillation. Hence, the initial resonance frequency corresponds to the minimum energy state and is therefore the most likely to be stimulated, as shown by equation (1).

4 Deflection Limitation

The post-installation deflection of concrete floor slab components, which may cause damage, is determined by the sum of the long-term deflection caused by fixed loads and the instantaneous deflection caused by live loads. This total deflection is equal to L/480, where L represents the span of the floor slab being examined. The deflection limit for serviceability should be tailored to suit the specific characteristics of the structure, its intended purpose, the kind of load it is subjected to, and the components that rely on the structure for support. The maximum deflection limit for wall-bearing beams or brittle finishes, with non-factorisedfactorized loads, is L/360 [3].

5 Fast Fourier Transform (FFT) in Accelerated Data Transformation

Fast algorithm development often involves using certain aspects of the algorithm to remove duplicate or superfluous operations from the direct implementation. Due to the periodicity, symmetry, and orthogonality orthogonally of basis functions and the specific interaction with convolution, the discrete Fourier transform (DFT) has huge ability to increase the efficiency of arithmetic.

There are four primary methodologies for devising effective DFT algorithms. The first two steps include partitioning the Discrete Fourier Transform (DFT) into many shorter DFTs. This is achieved in Multidimensional Index Mapping by the use of a multidimensional index map, whereas in Polynomial Description of Signal, it is accomplished using polynomial subtraction. The third technique involves factorizing signal processing operators, namely the DFT operator, into sparse factors. The concept of DFT as Convolution or Filtering involves the development of techniques that transform DFTs of prime length into cyclic convolutions. Another intriguing method involves recursively formulating the evaluation of Discrete Fourier Transform (DFT) in particular scenarios as the evaluation of DFT in terms of two half-length DFTs, each computed using a quarter-length DFT and so on [7].

The Fast Fourier Transform (FFT) is a mathematical algorithm used to convert time-domain acceleration data into frequency-domain signals. FFT decomposes acceleration data into complex exponential functions representing distinct frequencies. The Fourier Transform for processing acceleration data may be defined using the following formula [8][9]:

$$S(f) = \int_{-\infty}^{\infty} a(t)\, e^{-j2\pi ft} dt \quad (2)$$

Where, S(f) = signal in the frequency domain, a(t) (acceleration signal in the time domain), $e^{-j2\pi ft}$ (kernel function), f (frequency) and t (time).

6 Estimating velocity and deflection from acceleration data

The vibration velocity response is determined by the process of numerically integrating acceleration with respect to time. The deflection is then determined by doing a second integration. Nevertheless, in several instances, the conversion of the acceleration signal into velocity and displacement by means of integration does not always provide a dependable solution owing to uncertain beginning circumstances and inevitable noise. Moreover, the correction procedure used to rectify the estimated deviation caused by acceleration is prone to eliminating significant data, resulting in the

omission of some deflection measurements, particularly those pertaining to the lower frequency components of structural movement [3].

Filtering is often used to exclude high-frequency elements (low-pass filter) or low-frequency elements (high-pass filter). The use of filtering, either in conjunction with baseline correction or as a standalone technique, has been extensively employed and leads to enhanced precision in deflection estimations [10].

The FIR Equiripple Highpass Filter, optimized with a filter length, was implemented in two stages of 3/8 Simpson integration. This resulted in dynamic deflection values of 97.62% + 1.43% of the LVDT data [11].

7 Vibration Test

Vibration testing for structural condition evaluation is a diagnostic technique that aims to determine the true strength and level of degradation of a structure, hence detecting its integrity and degree of decay. Vibration testing is conducted to supplement visual examination by giving dynamic characteristics in the form of vibration frequency. Frequency is a quantitative assessment of the rigidity and cohesion of the structure. The association between the pace of degradation and the structural state may be determined by observing any periodic change in the dynamic parameter. Vibration testing is used to evaluate the condition of many kinds of bridges, including reinforced concrete, pre-stressed concrete, steel frame, and composite steel girder bridges [12].

The use of the real natural frequency for evaluating the state of the jetty structure is aimed at streamlining the study. The investigation in issue involves recalculating the natural frequency of the structure under examination using its dimensions [13].

The parameters for dynamic assessment are as follows [12]:

1. First natural frequency or measured fundamental, f_{actual} which comes from free vibration.
2. Flexural rigidity, EI_{actual}
3. Critical Damping, ζ_{actual}

The reduced rigidity in two planes – vertically and horizontally - makes the decks of the footbridges to be exposed to the phenomena of excess vibrations or even to get into resonance with direct consequence on the comfort of movement of the pedestrians or in extreme situations that of the collapse of the construction [14].

7.1 Relative Structure Damage Value

A reduction in the observed natural frequency compared to the expected natural frequency value indicates a decline in the structural integrity. The structural reaction is intricately linked to the state of structural damage. The values indicating the extent of structural damage are as follows [12]:

$$D_{realtive} = \frac{(f_{theoretical} - f_{actual})}{f_{theoretical}} \times 100\% \quad (3)$$

Where:
$D_{realtive}$ = relative structure damage value
f_{actual} = actual natural frequency [Hz]
$f_{theoretical}$ = theoretical natural frequency [Hz]

7.2 Capacity Loss Value

The capacity decrease value may be approximated by using the below equation [12]:

$$D_{kap} = \frac{(EI_{teoritis} - EI_{aktual})}{EI_{teoritis}} \times 100\% \quad (4)$$

Where
$D_{capacity}$ = capacity loss value
$EI_{theoretical}$ = theoretical bending stiffness [kN.m^2]
EI_{aktual} = actual bending stiffness [kN.m^2]

$E_{dinamis}$ obtained by the following formula [12]:

$$E_{dinamis} = \frac{E_{elastis} + 19.10^6}{1.25} \ [kN/m^2] \quad (5)$$

7.3 Critical Damping Analysis

The determination of critical damping is achieved by the use of the following formula[15], [16]:

$$\zeta = \frac{\delta}{2\pi} = \frac{1}{n}\frac{1}{2\pi}\ln\frac{A_o}{A_n} \times 100\% \quad (6)$$

Where:

δ = logarithmic decline
n = number of oscillations
A_o = 1st Amplitude
A_n = nth amplitude

8 Research Methodology

The study was carried out on a Jetty structure located on one of the islands in the Kepulauan Seribu one of the islands in the Kepulauan Seribu, where there were signs of structural collapse in the construction. This research conducted a comprehensive examination of the structural characteristics of piles, pile caps, and slabs. The structural conditions were visually assessed and examined by the use of hammer tests and vibration testing, as shown below:

Fig. 2: Rapture of the pile head results in reduced rigidity between the pile and the pile cap. One of the causes is that the concrete is not well integrated, resulting in corrosion of the reinforcement.

Fig. 3 :The eccentricity of the pile against the pile caps results in forces that are not in accordance with the plan.

Understanding the behavior of a structure when subjected to an external force or oscillation is crucial for conducting structural analysis. The natural frequency of a structure, determined under the assumption of no damping or loading, only depends on the beginning circumstances and serves as a numerical representation of the structure's behavior. This is often known as a free vibration analysis [17] . Dynamic tests were conducted in order to determine if the frequency accurately reflects the state of the structure. Following field-based dynamic testing, computerized numerical testing employing FFT was then performed. Smartphones can be used as tools for assessing dynamic vibrations caused by pedestrian loads, where the dynamics due to human footsteps are difficult to measure with traditional sensors [18]. The accelerometers in combination with gyroscopes are used to construct inertial measurement units. Also a GPS receiver along with the measurement system and extended Kalman filter algorithm can be used to measure the position of the automobile .The gyroscope in smartphones can record real-time vibrations, which are easy to use, analyze, and share, overcoming the limitations of traditional sensors [19].

The jetty vibration data was obtained by measuring the acceleration caused by environmental loads such as strolling people and sea waves. The specific vibration acceleration data may be seen in the picture below:

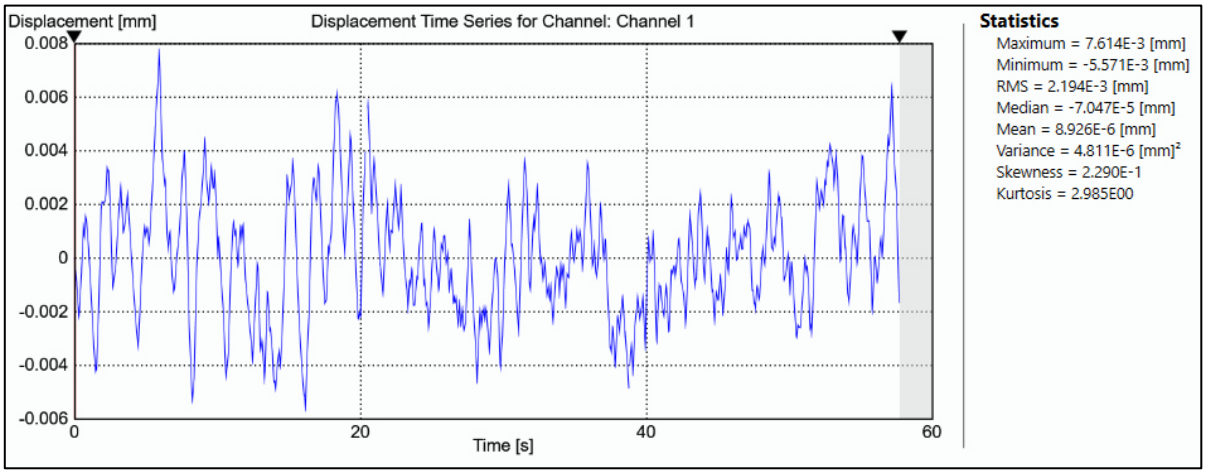

Fig. 4: Y-direction dynamic deflection (transverse jetty)

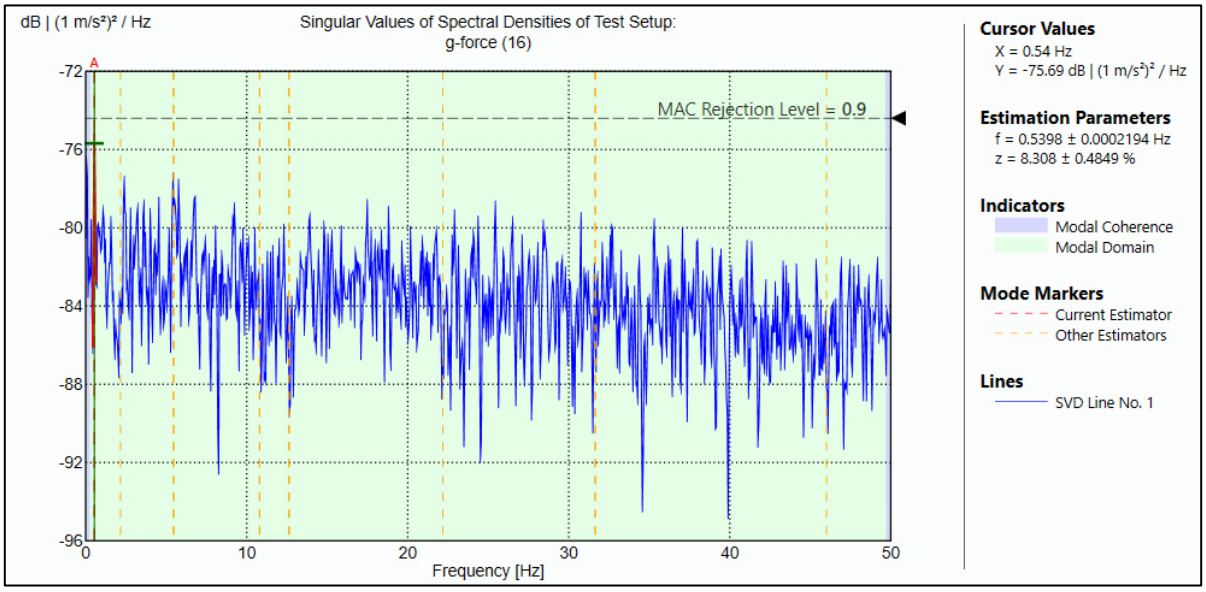

Fig. 5: Y-direction natural frequency (transverse jetty)

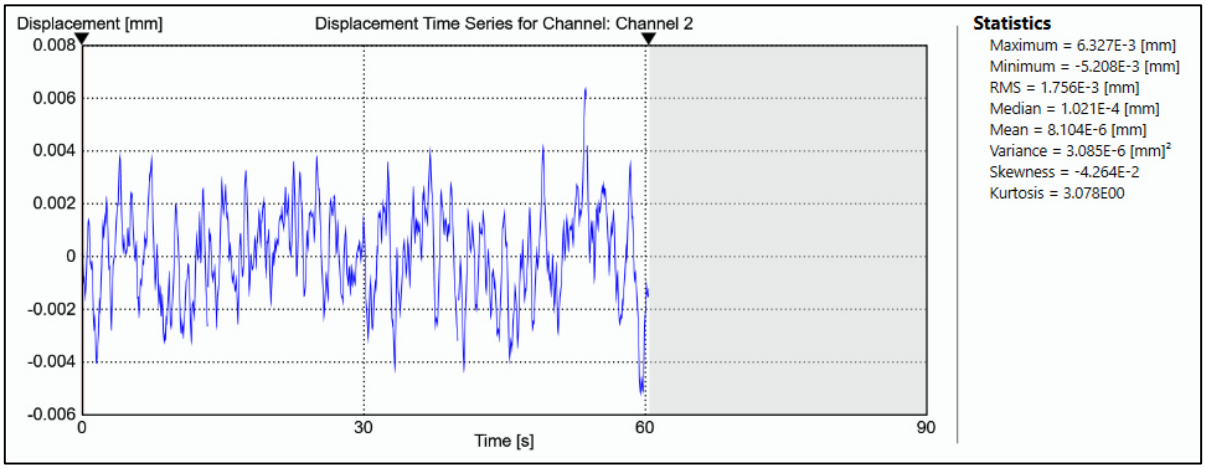

Fig. 6: x-direction dynamic deflection (longitudinal jetty)

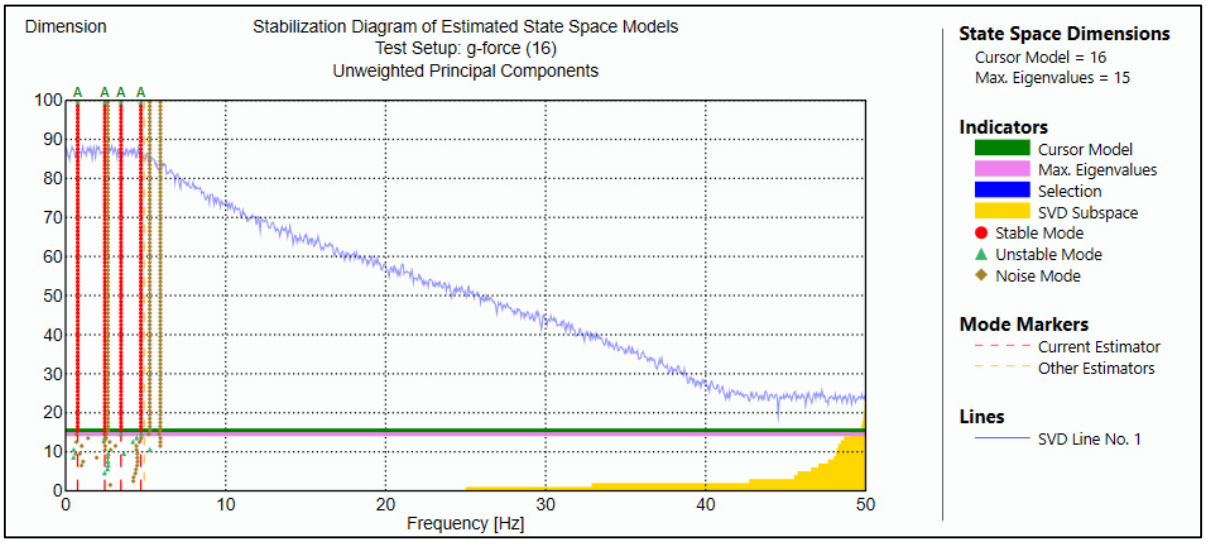

Fig. 7: x-direction natural frequency (longitudinal jetty)

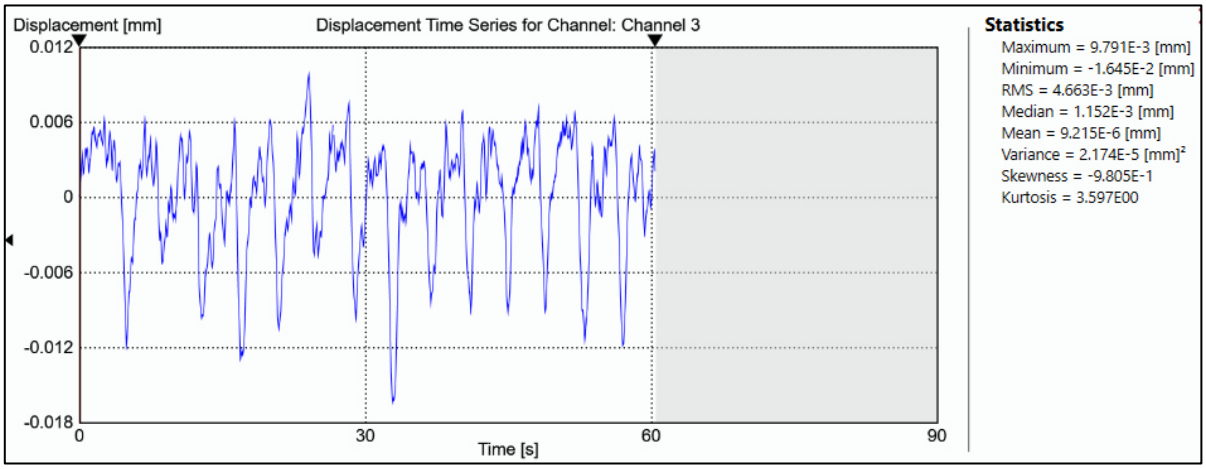

Fig. 8: z-direction dynamic deflection (vertical)

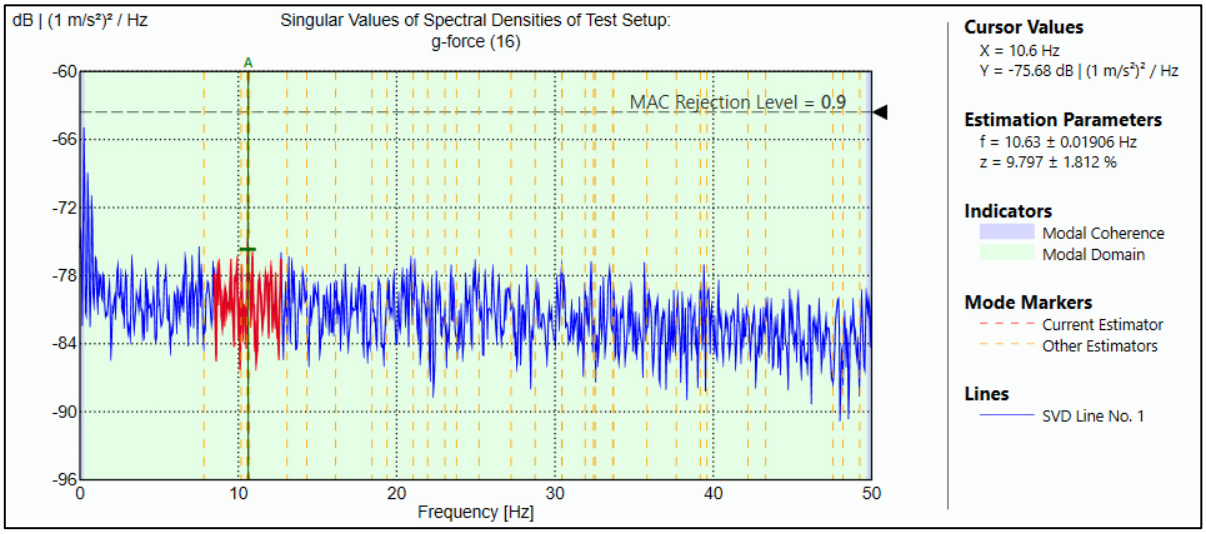

Fig. 9: z-direction natural frequency (vertical)

The natural frequency of the subsequent test results is compared with the analytical frequency, where the structural model uses the design material quality. The planned natural frequency is obtained from the analysis of the jetty model according to the actual geometry in the field, with element

dimensions, conditions, and ideal quality as specified in the technical specifications. The analytical natural frequency of the model is provided in the table 2:

Table 2: Natural frequencies of analytical jetty jettys

Mode	Frequency	Period	UX	UY	UZ	RX	RY	RZ
Shape	Cyc/sec	Sec	Unitless	Unitless	Unitless	Unitless	Unitless	Unitless
1	1.090	0.917	0	0.884451	0	0.21518	2.277E-20	0.116003
2	1.100	0.909	0.999997	0	1.988E-10	0	0.006503	1.269E-20
3	1.103	0.906	1.097E-20	0.115521	0	0.027873	0	0.883971
4	7.069	0.141	0	5.101E-07	5.966E-19	4.968E-06	9.578E-18	1.065E-07
5	17.268	0.058	2.988E-20	8.718E-10	7.246E-17	2.86E-07	2.742E-17	1.358E-10
6	26.895	0.037	9.248E-19	6.911E-06	1.668E-15	0.190517	5.139E-15	0.000011
7	26.990	0.037	1.005E-06	1.512E-19	0.062235	4.486E-15	0.18868	1.181E-19
8	27.314	0.037	2.423E-19	0.000011	1.354E-15	0.315557	4.004E-15	0.000012
9	27.708	0.036	1.856E-19	8.149E-06	2.73E-16	0.225114	6.956E-16	1.338E-06
10	27.955	0.036	1.821E-19	3.004E-08	5.192E-16	0.000835	9.33E-16	6.027E-07
11	28.035	0.036	6.841E-09	0	1.738E-06	2.748E-16	0.000667	0
12	28.249	0.035	1.773E-20	6.961E-07	2.45E-18	0.019268	7.765E-17	2.535E-08

The dominant mode shapes in the y direction (mode 1), z direction (mode 2), and z direction (mode 7) are sequentially shown in Figures 12, 13, and 14.

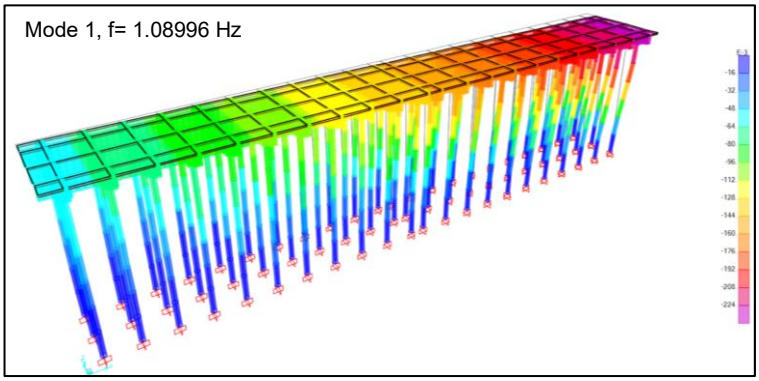

Fig. 10: Mode shape-1 theoretical at y-direction (transverse jetty)

Figure 10 shows the mode shape in the y direction with a theoretical frequency of 1.08996 Hz for the ideal structural condition as per the design. Meanwhile, the natural frequency obtained from the testing is 0.67 Hz (as shown in Figure 5). This indicates that the actual structural stiffness is lower than the design plan.

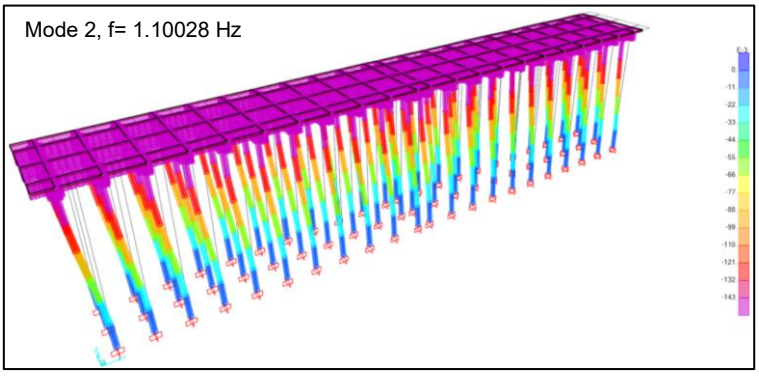

Fig. 11: Mode shape-2 x-direction (longitudinal jetty)

Similarly, Figure 11 shows the mode shape in the x direction with a theoretical frequency of 1.10028 Hz for the ideal structural condition as per the design. However, the natural frequency obtained from the testing is 0.5398 Hz (as shown in Figure 7). This indicates that the actual structural stiffness is lower than the planned design.

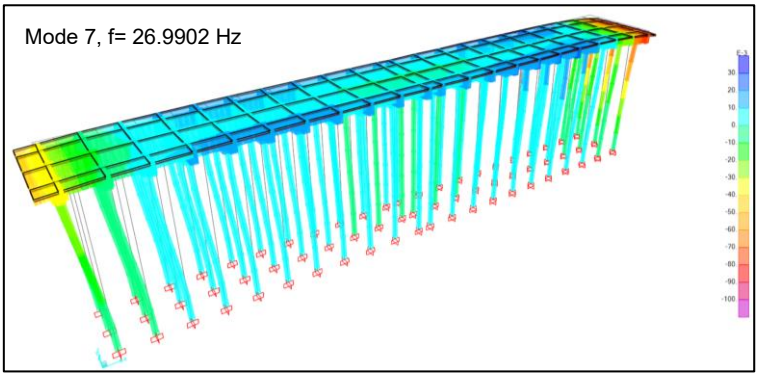

Fig. 12: Mode shape-7 vertical z-direction)

The same applies to the z direction as shown in Figure 12, where the theoretical frequency is 26.9902 Hz, while the test result frequency is 10.6 Hz (as shown in Figure 9). The lower stiffness compared to the design will inevitably have implications on the structure's static deflections and vibrations.

9 Discussion and Result

The test findings' natural frequencies are then compared to the analytical frequencies, using the structural model employing the specified material quality for design purposes. The model's natural frequencies are shown in table 2.

The dynamic deflections derived from the double integration of acceleration data [11], as presented in Figure 4, Figure 6, and Figure 8, along with the peak deflections and frequencies from Figure 5, Figure 7, and Figure 9, were overlaid onto the standard compliance graph depicting vibration levels for comfort and health [2]. This analysis yielded the following outcomes:

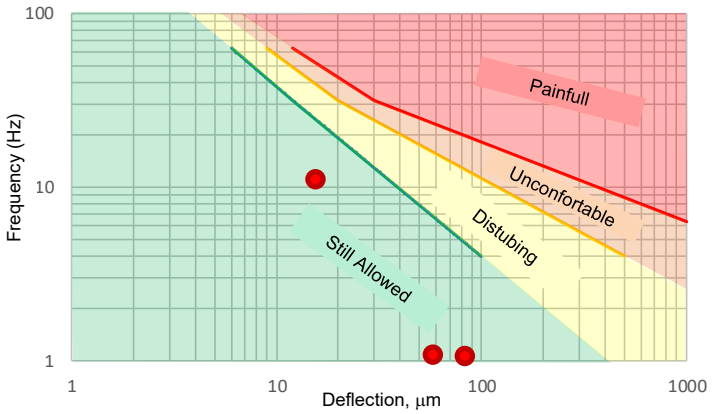

Fig. 13: Vibration Level Standards for Comfort and Health [2]

The graph (Figure 13) illustrates that the vibration experienced at the jetty, caused by both the load of pedestrians walking and the wave load during testing, remains below the permissible thresholds. In addition, a comparison is conducted between the analytical and testing value to assess the relative damage and capacity reduction. The results are presented in the following table 3:

Table 3: Dynamical Parameters of Plan Design and Actual

Type	$f_{theoritical}$ Hz	f_{actual} Hz	$E_{dynamic}$ design kN/m²	$E_{dynamic}$ actual kN/m²	Relative Damage Value $D_{realtif}$	Capacity Decrease Value D_{kap}	damping ratio ζ(%)
x-direction	1.10028	0.5398	25484084.4	10693000.9	50.94%	58.04%	8.308
y-direction	1.08996	0.67	25484084.4	10693000.9	38.53%	58.04%	9.134
z-direction	26.9902	10.6	25484084.4	10693000.9	60.73%	58.04%	9.797

Frequency is a measure of structural stiffness and integrity. Any periodic changes in dynamic parameters provide a correlation between the structural condition and the rate of damage. The flexural stiffness parameter (EI) is directly related to the actual natural frequency. A reduction in the actual flexural stiffness, compared to the theoretical flexural stiffness, indicates a decrease in load-bearing capacity. A reduction in the actual frequency by 10-20% compared to the theoretical frequency indicates a fairly poor condition. This range is equivalent to a decrease in the actual flexural stiffness by 20-40% compared to the theoretical stiffness.

The presence of fractures in the concrete leads to a high damping ratio due to the absorption of energy. The essential damping ratio of intact concrete ranges from 2% to 5%. The critical damping ratio of cracked concrete ranges from 7% to 10% [12]. According to the damping ratio data, Table 7 indicates that the concrete is broken in all three directions: x, y, and z.

According to the findings of these assessments and as outlined in the Guidelines for the Assessment of Bridge Conditions for Superstructures by Means of Vibrating Tests in terms of Relative Damage Values and Decreased Capacity [12], the jetty is deemed to be in a state of bad condition and has suffered significant structural damage.

6 Conclusion

This study demonstrates that the vibrations experienced on the jetty due to the combined effects of pedestrian movement and waves remain within acceptable thresholds. However, considering the dynamic properties of natural frequency and damping, the jetty is deemed to be in a state of significant deterioration, with structural damage ranging from 38.53% to 60.73% and a corresponding decrease in its load-bearing capacity by 58.04%. The jetty structure is deemed non-functional due to its failure to comply with the Security, Safety, and Sustainability Standards outlined in the preceding paragraph, thereby classifying it as a building failure. By using Fast Fourier Transform (FFT) to analyze the natural frequency readings and comparing the resulting deflections, it can be concluded that the frequency data is reliable and cannot be misleading.

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