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Transformative Resilience in Port Infrastructure: Behavior Analysis of the New Oil Dolphin Quays Access Bridge at Bandar-e Anzali

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Abstract: Efforts are underway worldwide to revolutionize port facilities in light of global efforts to enhance port efficiency. Due to their pivotal role in shaping national vitality, port infrastructures need meticulous planning for alterations. There are a variety of applications for quay structures, including dry access to maritime areas, vessel berthing, and mooring, among others. The piled trestle configuration of the Bandar-e Anzali quays prompts an in-depth examination of the bridge structure for the new oil dolphin quays. Taking a comprehensive approach, this study examines the intricate interplay of geotechnical and seismic conditions. Using SAP 2000 software to model the access bridge structure meticulously, the study is grounded in a thorough understanding of foundational dynamics. Structural analysis is the main component of the investigation, navigating a wide range of loads and their intricate combinations. As a result, the study reveals the bridge's inherent stability, with stress ratios across all piles harmoniously convergent within acceptable thresholds. Essentially, this research highlights the convergence of scientific rigor, engineering expertise, and architectural vision. As well as demonstrating the stability of the access bridge, this study contributes to a broader discourse about the sustainability of port facilities at the intersection of economic progress and maritime connectivity. In a world of transformative infrastructure, the Bandar-e Anzali oil dolphin quays are a testament to a harmonious coexistence of science, innovation, and global connectivity.

Keywords: component; Port infrastructure, Quay structures, Structural analysis, Geotechnical conditions, Seismic assessment, Sustainability.

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1. INTRODUCTION

The port of Bandar-e Anzali is situated in the northwestern region of Iran within the province of Gilan, strategically positioned between the Caspian Sea and the biologically significant Anzali Wetland. Depending on the categorization and projected magnitudes of commodities traversing its shores, the development blueprint for this port is meticulously shaped, thus requiring the design of quays that can accommodate various vessel types, including containers, general cargo carriers, and oil tankers [1,2]. Three oil dolphin quays are especially noteworthy because they facilitate the berthing of oil-carrying vessels.

In a recent study by Khodadadi Koodiani et al., the authors developed and optimized a neural network model to accurately predict the compressive strength of FRP-confined columns, offering valuable insights into the structural behavior of fiber-reinforced polymer (FRP) composite materials in construction and engineering applications [3].

In a study by Joushideh et al., the application of Ground-Penetrating Radar (GPR) for characterizing scour-induced subsurface deformations in port structures with contiguous pile walls was investigated, shedding light on the structural integrity of quay systems.[4]

Dolphin-type quays integrate a diverse array of elements, including an access bridge, platforms for loading and discharging, and mooring dolphins with specialized berthing amenities. In addition to providing vital connectivity between the platform and the access path aligned with the breakwater, the access bridge extends approximately 30 meters in length and 7.5 meters in width. As a matter of elevation, the level of the deck on this bridge is meticulously situated at 2.3 meters above mean sea level in Bandar-e Anzali [5,6]. This bridge's construction narrative is further complicated by the timing of its realization - after the completion of the breakwater infrastructure [7]. Instead of requiring pier piles, this innovative approach employs a foundation dimensioned to meet the unique requirements of this scenario [8], eliminating the need for the initial set. Applied to marine engineering and infrastructure design, this methodology exemplifies the vanguard principles espoused by contemporary engineers. Mahmoudabadi's work in 2021 delved into the utilization of viscous dampers for the retrofitting of reinforced concrete frames, demonstrating innovative approaches to enhancing the seismic resilience of key structural elements in port facilities [9].

With its intricate and expansive infrastructure, Bandar-e Anzali port stands as a testament to the seamless mixture of indigenous wisdom and scientific acumen in coastal and marine management [10,11]. Furthermore, the application of innovative engineering techniques, such as Fiber-Reinforced Polymer (FRP) confined columns and seismic-oriented design strategies [12], stands as an important mechanism for ensuring the port's edifices are resilient and long-lasting. A recent review article provides an insightful examination of concrete recycling, addressing the environmental challenges associated with the significant generation of concrete waste in construction and exploring sustainable approaches by incorporating waste materials into concrete mixes [13].

In a 2020 study by Mahmoudabadi, the behavior of cables with two spring-dampers and one viscous damper was thoroughly examined, offering valuable knowledge about the dynamic response of critical components within port infrastructure [14]. Figure 1 illustrates the overarching blueprint of these oil dolphin quays, which is the culmination of meticulous strategizing, innovative design paradigms, and rigorous analytical scrutiny [15]. As a result of the sweeping tides of climate change and the potential for maritime mishaps [16], the structural robustness of these buildings assumes paramount importance. Ingenious consideration has been given to the impact of surface irregularities on the malleability of corroded steel plates immersed in marine environments [17,18], as well as the sturdy construction of rubble mound breakwaters.

A recent study conducted a comprehensive analysis of pseudo-static slope stability and numerical settlement assessment of rubble mound breakwaters under hydrodynamic conditions, providing valuable insights into the resilience of port infrastructures facing coastal erosion challenges [19].

These precautionary measures, in addition to safeguarding the port's operational efficiency, serve as a steadfast contribution to the seismic endurance of these architectural wonders [20,21], a parameter that gains added significance in this geographical area due to its seismic vulnerability [22]. In order to ensure the resilience and longevity of these structures under diverse environmental and operational conditions, dynamic evaluation, encompassing a range of stochastic influences [23], is a necessary part of the life cycle assessment process.

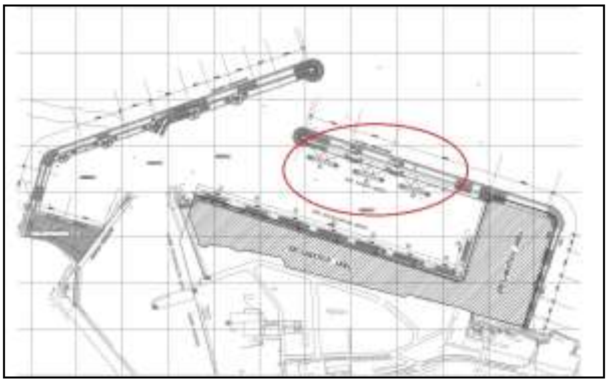

Figure 1. Spatial Configuration of Oil Dolphin Quay Positions.

2. STRUCTURAL CONFIGURATION OF THE BRIDGE

The access bridge core foundation consists of a harmonious amalgam of essential components designed to ensure both stability and functionality. It explores the complex interplay of diverse elements that underlie the bridge's robustness by analyzing its structural framework. Through a well-conceived framework of two discernible piers and an anchoring foundation, the access bridge manifests its architectural prowess as a vital conduit between the terrestrial realm and maritime infrastructure. The precise engineering and material finesse of each of the piers serves as the real cornerstones of this architectural masterpiece. There are three vertical supports, each meticulously arranged in concert to synergize their load-bearing abilities.

Transverse concrete beams connect these vertical pillars of strength, displaying seamless material and design integration. As well as serving as a crucial location for load distribution and dispersion, this concrete beam provides unity between the steel piles. With steel plate girders constructing the longitudinal girders, the structure is effectively channeled and distributed by the longitudinal girders. The axial strength of the steel piles creates the equilibrium of vertical load-bearing capacity, transferring and balancing the various loads exerted on the bridge. A variety of piles provide multifaceted flexural capabilities, while strategically arranged transverse concrete girders provide lateral stability. Despite dynamic external pressures, these girders ensure steadfast stability even with strategically positioned horizontal forces.

The construction sequence unfolds as a meticulously choreographed symphony from conceptual to tangible realization. Steel piles are meticulously driven into the earth's receptive embrace in the first phase of structural execution, each plunge reflecting engineering precision. On top of the steel pillars, precast concrete caps serve as foundational keystones, serving as keystones for the elements to come. In the next phase of construction, the precast concrete formwork is deliberately positioned to herald the impending arrival of the transverse beam, which shealds the beginning of the ballet of construction. As the structural arteries breathe life into the edifice, this structural element is finely tuned to facilitate lateral stability. Concrete for the transverse beam is poured on top of the steel foundation, forming a balletic fusion of materials and design that serves as the foundation for the subsequent layers of architectural excellence to be built upon.

As a continuation of this symphonic journey of construction, steel girders, true embodiments of engineering prowess, are positioned with a seamless sense of purpose, signaling the beginning of the next phase. Taking into account the meticulously selected locations in which these girders will be installed, further entangling the structural integrity of the bridge with the architectural finesse that pervades every aspect of it. In the final crescendo of this orchestrated installation, the in-situ casting of the bridge deck slab culminates in an act of architectural alchemy which binds materials into a solid amalgam of form and function that will last for generations to come. I would submit that in summation, the structural system of the access bridge is not only an example of engineering ingenuity, but also serves as a microcosm of how meticulous design, careful material selection, and careful construction orchestration work together to create a truly magnificent architectural work of art. In the grand tapestry of scientific acumen and creative vision, each of the steel piles, each of the concrete beams, and each of the steel girders is a brushstroke of a grand tapestry. As an embodiment of the transformative potential of engineering, the Bandar Anzali access bridge stands not just as a conduit but as a bridge unifying scientific principle and tangible reality in pursuit of maritime connectivity, a bridge that merges scientific principle with tangible reality.

3. METHODOLOGICAL FRAMEWORK FOR DESIGN

Designed with a combination of scientific rigor and engineering ingenuity, the access bridge is a result of a combination of scientific rigor and engineering ingenuity where materials, forces, and structures are meticulously orchestrated to ensure optimal performance, safety, and durability. There is a large section in this chapter that delves into the overarching design methodology woven into the fabric of this architectural marvel, unraveling the threads of design philosophies that have been woven into the design.

Due to the fact that the pivotal elements of the access bridge are steel piles and longitudinal girders, a careful selection of the design methodologies becomes very important given the structural composition of the bridge. The guiding principle is the harmonization of materials and forces. This is a dance choreographed by structural design principles that ensure the equilibrium and resilience of the structures under consideration. Sculpted from the resilient embrace of steel, the structural components form the very essence of this architectural ensemble's design, demanding a nuanced approach to their design, thus requiring a nuanced approach to construction.

It is evident that when it comes to the design of the steel piles and longitudinal girders that are intrinsic to the bridge's functionality, the compass of choice points toward the realm of permissible stress designs. This method, which is grounded in the principle of ensuring that the stress levels within the structural components keep within permissible limits, encapsulates the delicate balance that needs to be reached between maximizing the load-bearing capacity and safeguarding against material failure at the same time. There is a synergy between the principles of physics and the parameters of engineering when stress, material properties, and load dynamics interact to shape the contours of design, providing an elegant synergy between engineers and physicists.

While steel is an important component of the symphony of design, it is not the only one to reach its crescendo. Among the components that act as a bridge between steel and earth, the concrete deck slabs and the concrete transverse girders, are imbued with a design methodology that incorporates the inherent strength and material properties of each of these components. This is where the ultimate strength design method steps into the narrative, taking advantage of the power of comprehensive analysis in order to scrutinize both the concrete deck slab and the concrete transverse girders. Using this method, we are able to navigate the intricate interplay between the ultimate load capacities of materials, and their inherent strengths, to produce an outcome that accentuates both structural integrities, as well as preserving the delicate balance between performance and safety.

In the process of crafting the access bridge, a nuanced approach was taken to take into account permissible stress design and ultimate strength design for distinct components. As a result of this pluralistic strategy, each parameter of the design is aligned with its most appropriate counterpart, thus acknowledging the multifaceted nature of architectural compositions. As part of the design process, it emphasizes the careful orchestration of various design theories, meticulously matched to the specific properties and roles of each structural element within the larger structural ensemble. To put it simply, the design methodology underlying the access bridge is a testament to the intricate balance between scientific principles and engineering pragmatism that goes into an engineering project. There is more to choosing the right design methodology than merely deciding what works for the project; it is a statement that the architectural entity is committed to the well-being and functionality of its inhabitants. There is a deep harmony that resonates within the very foundations of the Bandar Anzali Bridge, a cadence that connects the theoretical principles and tangible structures, enabling a seamless transition between theoretical principles and tangible structures.

4. GEOTECHNICAL SUBSTRATUM ANALYSIS

There is no doubt that the geotechnical canvas upon which any engineering endeavor rests is integrally related to the foundation of that endeavor. Throughout this section, we will delve into the geotechnical conditions that provide the foundation for the design of the oil quay, which functions as an unyielding substratum on which the design depends. There is an intricate relationship between soil dynamics and architectural stability, as revealed by an investigation of layering and geotechnical parameters.

A simple glance at Table 1 is sufficient to demonstrate the extent to which the geotechnical landscape that determines the design of the quay has been thoroughly analyzed. There is a comprehensive tableau that illustrates the stratification of soil layers, each stratum encompassing a unique geological narrative that has been meticulously analyzed and deciphered through the process of scientific inquiry. There are fundamental tenets that inform the rationale for the design of the quay. These tenets inform the characterization of soil types, their respective thicknesses, and classifications of soil types.

Table 1. Layering and Geotechnical Parameters of Soil Layers for Quay Design.

Qualitative/Quantitative Description	Geotechnical Parameters
Sand	Soil Type
From Ground Surface to Bottom of Layer	Layer Thickness (m)
SM or SP-SM	Soil Classification
Medium to Dense	Soil Description in Terms of Compaction
1.7	Dry Unit Weight (t/m³)
30	Effective Friction Angle (°) φ
0	Effective Cohesion (t/m²)

There are nuances of soil dynamics that are communicated with precision through the terminological intricacies of geotechnical discourse. In order to ensure that geotechnical terms are tethered to specific contexts and adhere to technical conventions, it is imperative to acknowledge that they are invariably tethered to specific contexts. As a result, the purpose of Table 1 is to provide a conduit through which a comprehensible narrative underpins the design process by channeling the difficult language of soil mechanics. There is a need, however, to instill a tangible connection between abstracted tables and classifications that are abstracted from the physical world. There is a close connection between soil behavior under varying loads, dynamic forces, and environmental conditions, which materializes in a meticulous assessment of soil behavior. When it comes to fostering equilibrium and longevity, it is imperative that the structural load-bearing components of the quay interact with the subterranean geological strata that support them.

The symphony of geotechnical conditions is composed of notes, and each parameter is composed into a stanza, creating a melody that encompasses all the intricacies of the subsurface. Architects orchestrate an intricate ballet between the terrestrial world and the man-made world within the context of the cohesion between design and soil dynamics. A testament to the harmony between the forces of nature and the ingenuity of humans can be found in the foundation of the oil quay, which was conceived within the crucible of geotechnical conditions. The journey through geotechnical conditions gradually leads to the realization that the table is merely one manifestation of a much larger subterranean world, as the series of geotechnical conditions concludes. As the layers of this world are layered upon each other, reverberating with the strains of geological history, carrying the resonance of millennia within them. As a result of the geological heritage and the architectural innovation of the oil quay, this world becomes the crucible within which the design of the oil quay takes shape.

Throughout the next section, we will examine more closely the intricacies of the design methodologies, the construction processes, and the seismic resilience of buildings. With this exploration, the oil quay at Bandar Anzali emerges as more than just a functional structure, but as one that embodies a harmonious dialogue between geotechnical forces and structural prowess for which the quay is both an embodiment and a catalyst for future development. In a symphony of equilibrium and engineering excellence, this building is a testament to the intricate relationship between the terrestrial realm and the architectural realm, where each support and shapes the other in a symphony of harmony and design excellence.

5. EXPLORATION OF ALLOWABLE PILE PENETRATION DEPTH

An intricate tapestry woven by structural engineers is that the very foundations upon which architectural endeavors stand, as well as the depths to which they reach, are intertwined within the intricate tapestry of structural engineering. In order to understand the subtleties that underlie the design of the oil quay structures, it is necessary to delve into the realm of the permissible pile penetration depth, a realm where engineering precision intertwines with geological responsiveness. There is a fundamental concept at the core of this investigation that can be described as pile length: a concept that transcends mere verticality to comprehend the implications of lateral load-bearing dynamics to a profound degree. This is due to the towering height of the piles adorning the oil quay structures, as this determines their lateral stability in the face of the diverse forces that interact with them. Computer modeling is complex, but it is essential that a judicious abstraction is made. This is a virtual penetration depth that incorporates pile behavior's myriad complexities.

It is evident that the determination of permissible pile penetration depth in both cohesive as well as granular soils is a delicate process that unfolds through the delicate cadence of equations, which is concisely represented by Zf.

$$z_f = 1.8T, \qquad T = \sqrt[5]{\frac{EI}{n_h}}$$

It is this mathematical realm that guides the traveler through a journey that is guided by parameters that resonate with the essence of a material's properties and the response of soil to the material. There is a complex interplay of variables in this equation, an intricate symphony of variables, which draws upon the modulus of elasticity (E) and the moment of inertia (I) of the pile, along with the coefficient of soil stiffness increase (nh), a parameter that resonates with the intricate interplay between soil and piles. As a result of the intricate equation, empirical relationships, as well as the soil type characteristic of the particular location weave their influence into the ultimate value of the coefficient of soil stiffness increase (nh) as a result of an assumed 1400 N/m3 for the coefficient of soil stiffness increase.

As a result of this equation, the permissible depth at which a pile can penetrate into a quay's oil platform is numerically rediscovered for the steel piles on the quay, which have a diameter of 34 inches and a thickness of 16mm. A careful calculation, based on the intricate interplay between the material attributes and soil dynamics, is carried out to determine a permissible penetration depth for the platform that serves as a sentinel guarding the integrity of the structure.

$$z_f = 1.8 \times \sqrt[5]{\frac{2e^{8} \times 3.779e^{-3}}{1400}} = 6.33$$

A numeric embodiment of the harmonious convergence between the structural prowess and the geological receptivity is the 6 meters, the depth at which pile penetration is permitted with resolute mathematical precision. There is a real sense that this depth, chosen consciously, extends its influence not only to the platform but also to the access bridge, forming a seamless continuum that spans both architectural entities simultaneously. In order to ensure that the harmony between depth and height is maintained, this calculated depth, infused with both empirical wisdom and mathematical precision, operates within the framework of a design reference level established at -11 meters, which ensures that the depth and height will be connected in an appropriate manner. It is clear from the above discussion that the meticulous determination of the permissible pile penetration depth is more than a mathematical exercise; it is a demonstration of the ability to combine engineering precision with geological responsiveness. Ultimately, the oil quay structures pivot upon the depth that emerges from a crucible of equations and material attributes, the fulcrum upon which the oil quay structures rest. As we continue our journey, the discovery of depth is just one note in a grand symphony of design and engineering that shapes the oil quay structures, a testament to the harmonious interaction of human ingenuity and the dynamics of nature.

6. MODELING AND SIMULATION

There is no doubt that the foundation of modern engineering lies in simulation and modeling, where intricate structures and dynamic forces are brought to life in a virtual world that mirrors reality in a way that represents the underlying physical reality. The aim of this section is to reveal the sophisticated methodologies that were employed for the modeling and simulation of the access bridge, in order to provide a glimpse into the sophisticated tools employed for unraveling the intricate details of the design.

6.1 Computational Framework

For the modeling, analysis, and design of the access bridge structure, a comprehensive computational framework from the ANSYS software suite, version 20.2.0, is at the center of the modeling, analysis, and design process. As a paragon of the theoretical world of computational engineering, the software acts as a conduit into which the intricate interactions between materials, geometries, and forces can be interrogated numerically and meticulously dissected using this software, a paragon of the theoretical world of computational engineering. This digital expanse of ANSYS can be compared to a virtual laboratory wherein architectural visions can be submitted to the rigors of computational exploration in order to reveal their dynamic responses to various loads and scenarios in the absence of a physical model.

6.2 Geometric Representation

As a result of the application of finite element modeling to the access bridge, a construction marvel combining steel piles, concrete girders, and intricate supports, has become a digital representation. Taking advantage of numerical simulations, this geometric representation, which is composed of a mosaic of nodes and elements, captures the complex interplay between structural components as they are represented through a geometric representation. It is the finite element analysis which forms the basis for this modeling strategy with each element representing a discrete sub-section of the bridge, adhering to the fundamental principles of continuum mechanics in its design. Throughout this geometric model, which has been meticulously structured, steel piles, longitudinal girders, and transverse girders have been meticulously translated into finite elements because of their meticulous representation. As this structure is comprised of several elements which are interconnected electronically, these nodes act as anchors for virtual forces to pass through, allowing a deeper understanding of how the bridge reacts to a range of loading scenarios. The three-dimensional model of the access bridge is depicted in Figure 2.

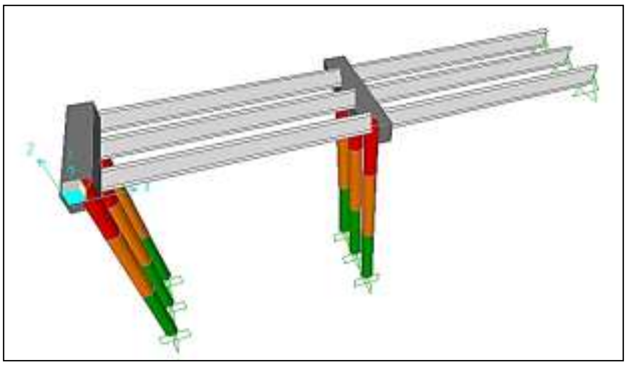

Figure 2. Three-Dimensional Model of the Access Bridge Structure.

In the characterization of pile sections, to account for the corrosion effects in three different environments: within soil, within water, and above water, thickness reduction of the pile wall has been considered as 1 millimeter, 3 millimeters, and 6 millimeters, respectively. Furthermore, in defining the cross-sections of longitudinal steel beams, a thickness reduction of 1 millimeter on each side of the section due to corrosion has been taken into consideration.

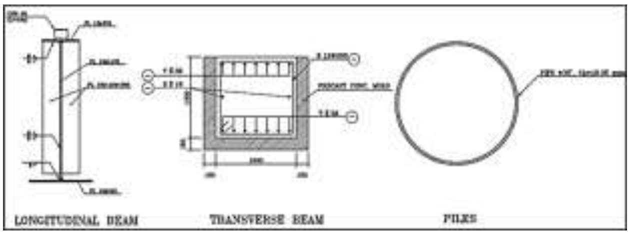

Figure 3. Cross-Sections of Structural Elements in the Access Bridge.

6.3 Material Attributes and Constitutive Models

A material model is a representation that transforms a material from a mere piece of matter into a dynamic entity defined by a set of dynamic attributes and constitutive properties. In order to fully understand the intricate relationship between stress and strain, constitutive models, and mathematical formulations that encapsulate this metamorphosis, are employed to capture this metamorphosis. During the construction of the access bridge, the steel piles and concrete girders were adorned with these constitutive garments, which imbued them with material properties that reflected real-world conditions. The steel piles, one of the most crucial load-bearing components of a structure, are endowed with a variety of material attributes generated from established mechanical testing and characterized by stress-strain relationships. This gives rise to a digital replica that can mirror the deformations and reactions that are observed in the real world. In the same way, concrete girders are also subject to the same rigor of material properties, which are designed to encompass the complexities of concrete behavior under a variety of loading conditions.

6.4 Boundary Conditions and Loading Scenarios

As intricate as the model may be, the imposition of boundary conditions and loading scenarios ensures that it remains anchored to reality through the imposition of boundary conditions. Digital narratives are shaped by these real-world influences, lending them a resonance with actual behaviors in the real world. This type of boundary condition, which has been meticulously defined within the ANSYS framework, mirrors the physical constraints that are anchored to the foundations of the bridge.

As if orchestrating the forces of a symphony, the loading scenarios unravel with a flowing cadence that seems like the orchestration of forces in a symphony. There is a systematic process by which dead loads, live loads, and environmental pressures are systematically incorporated into the model, in order to simulate the dynamic forces that the bridge will encounter throughout the course of its operation.

In Figure 4, the visual tapestry of the digital realm is depicted - a dynamic depiction of nodes, elements, and forces, which define the behavior of the access bridge within the virtual expanse as illustrated in the dynamic depiction of nodes, elements, and forces.

This representation, which acts as a bridge between reality and virtuality, is an excellent example of how modeling and simulation can play a key role in the development of superior engineering solutions. It will be our goal to explore the domain of structural analysis in the following sections, where we will embark on a journey of validation and exploration as we explore the numerical constructs. With the help of modeling and simulation, we can analyze the intricate responses of the access bridge to forces both anticipated and unexpected, revealing the resilience and precision that underlie its architecture narrative through the lens of dynamic modeling and simulation.

7. LOADING SCENARIOS AND ENVIRONMENTAL DYNAMICS

In having to deal with a diverse range of loading scenarios and the ever-changing forces imposed by an ever-changing environment, the bridge's structural mettle is tested and shaped continuously by the intricate interplay of the two. There is a substantial portion of this section devoted to the scientific underpinnings of loading scenarios as well as the dynamic environmental forces which converge to determine the structural integrity and resilience of a bridge.

7.1 Live and Dead Loads

Two types of loads are considered paramount in structural analysis: the dead load, the weight of the architectural components, and the live load, the transient force of vehicular motion that moves the vehicle. The meticulous orchestration of these loads transcends mere calculations; it is a process that harnesses the principles of statics and the material's properties to show how the bridge will react under varying loads. Dead loads are calculated by considering each slab layer, from the thickness of the deck up to the asphalt overlay, when formulating dead loads. This elaborate dance encompasses the nuances of design considerations, including guardrail allocation and load distribution, when it comes to applying dead loads across longitudinal girders. Several calculations have been made, which represent a numerical representation of gravitational influence, which not only contribute to the foundational stability of the bridge, but also to the dynamic choreography of the distribution of live loads.

There is no doubt that live loads originating from vehicular traffic pose a transient force that cascades through the bridge's structure on a regular basis. In the Iranian Bridge Loading Code, this force is meticulously defined in order to present a mechanistic representation of the motion of vehicles. In order to provide a safe, balanced bridge, the load's interaction with its structural components is more than just a numerical calculation; it encapsulates the very essence of the bridge's function and its ability to bear dynamic forces while maintaining equilibrium at the same time.

Taking into account a slab thickness of 25 centimeters, an asphalt layer thickness of 5 centimeters, and a longitudinal steel beam width of 2.5 meters, the load imposed on the longitudinal steel beams due to the weight of the slab is calculated as follows:

$$P_1 = 0.3 \times 2.5 \times 2.5 = 1.875 \quad t/m$$

Assuming a concrete slab thickness of 30 centimeters at the location of guardrails and allocating 0.5 meters of the bridge slab width on each side for the installation of guardrails, the dead load imposed on the two adjacent longitudinal steel beams is calculated as follows: And the applied dead load resulting from the weight of components on the intermediate longitudinal steel beams is equal to:

$$P_1 = 1.875 \quad t/m$$

The load of pipeline pipes within a 3-meter width section of the bridge slab, designated for their passage, is considered to be 1 ton per square meter. Taking into account the width of the longitudinal side beams and the intermediate beams relative to the pipeline load, the lateral longitudinal beam and the intermediate longitudinal beam carry a portion of the total pipeline load. Therefore:

$$P_5 = 2/3 \times 3 \times 1 = 2 \quad t/m$$
$$P_6 = 1/3 \times 3 \times 1 = 1 \quad t/m$$

In the context of this study, P5 and P6 denote the respective contributions of the lateral and intermediate longitudinal beams to the pipeline load.

The live load applied to the bridge structure encompasses a standard truck load, adhering to the guidelines stipulated by the Bridge Loading Code. According to this code, the live load consists of two components for each lane of the bridge:

a)A truck weighing 400 kN with a length of 10 meters, leaving 3 meters empty space both in the front and rear portions.

b)Along the remaining length of the lane, a uniform load of 15 kN/m is distributed, covering an area with a width of 3 meters.

This live load distribution, as specified by the Bridge Loading Code, is illustrated in Figure 4. The combination of these load components provides a representative scenario for the impact of vehicular traffic on the structural integrity of the access bridge. Figure 4 serves as a visual portrayal of this live load distribution. This diagram not only encapsulates the geometric arrangement of the applied loads but also underscores the adherence to regulatory standards in assessing the bridge's response to dynamic traffic loads. The configuration displayed in Figure 4 exemplifies the meticulous approach taken to simulate real-world scenarios and evaluate the bridge's ability to withstand and distribute the effects of live loads, safeguarding both performance and safety considerations.

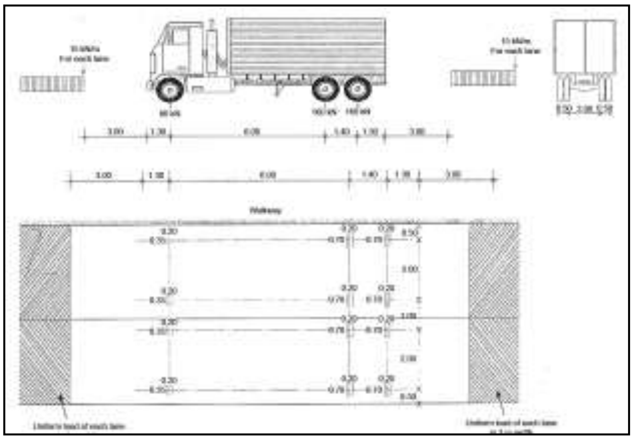

Figure 4. Standard Truck Loading

Truck loads entering each span of the bridge are analyzed for two cases: one causing maximum bending along the span and the other leading to maximum shear. The positions where the truck loads are applied are determined using influence lines for both bending and shear conditions. For transverse load distribution among the longitudinal girders, three scenarios are considered: the truck on the rightmost lane, aligned with the middle girder, and with the middle girder under its center. To distribute loads across the traffic path width, the bridge deck is modeled as a continuous transverse beam on support points corresponding to longitudinal girders. The reactions at these points are established for each scenario. These scenarios are illustrated in Figure 5. The load, denoted as P, represents the weight of a single rear axle and is 16 tons. In summary, precise truck load distribution analysis and its effects are crucial for understanding the structural behavior of the access bridge under different traffic conditions. Employing influence lines and adhering to load distribution standards provide a comprehensive framework that bridges theory and practical application, enhancing the bridge's overall integrity and performance.

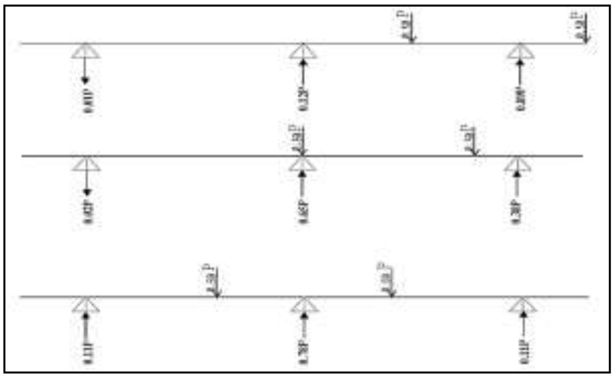

Figure 5. Distribution Scenarios of Standard Truck Load in Transverse Direction

The reactions at the supports in each of the three scenarios are depicted in the provided figure. Therefore, utilizing these reaction coefficients, the truck load is applied onto the longitudinal girders in both critical scenarios of maximum flexural moment and maximum shear force, under six load combinations labeled as Truck1 through Truck6. Furthermore, for applying the truck load in loading combinations, the impact factor must be considered. According to the Iranian Bridge Loading Code, the impact dynamic factor is determined using the following equation:

$$\delta = 1.3 - 0.005L - 0.15h$$

In this equation, h represents the embankment height on the bridge in meters, and L denotes the span length in meters. For the longitudinal girders, the impact dynamic factor is given by:

$$\delta = 1.3 - 0.005 \times 13.5 \cong 1.23$$

7.2 Environmental Dynamics

The dynamic forces imposed by the environment extend far beyond those that are imposed by static loads, creating a symphony of forces conducted by the elements themselves. An intricate ballet of forces is orchestrated by wind, water, and temperature, each of which imparts its signature on the bridge's behavior. This signature plays a crucial role in determining its stability and sturdiness. It was necessary to have a meticulous understanding of aerodynamic effects to be able to control the wind, the ethereal conductor of forces. In order to ensure that the bridge can withstand the tempestuous embrace of wind forces without compromising its structural integrity, the design considerations are guided by the assessment of wind-induced vibrations and flutter effects.

Another layer is added to the symphony of the environment by the nearby Caspian Sea, which serves as a living metaphor for the aquatic realm. It is essential that the bridge withstands the potential onslaught of salt-laden moisture, which necessitates consideration for the material's durability and protection against corrosion in the long run. This interplay between architectural form and the elements is a constant reminder of the dynamic interplay between architectural form and the elements as it is corrosive in marine environments. This bridge's behavior has been influenced by the fluctuations in temperature, a manifestation of Earth's rhythmic pulse as a result of its rotation and temperature fluctuations. Material expansions and contractions as a result of temperature variations require meticulous consideration within the design to accommodate these changes. It is important to remember that a bridge's structural response to thermal fluctuations is not just a calculation; it is a testament to the bridge's ability to adapt and endure even under the constant influence of changing environmental conditions. The next section of this paper deals with the realm of dynamic structural responses, where the numerical representation of the bridge is used to navigate the complexities of loading scenarios and environmental forces. The convergence of scientific inquiry and architectural design is at its zenith as the bridge's virtual counterpart, mirroring the interaction of forces, takes us on a journey of exploration and analysis of the forces at play.

8. LOAD COMBINATIONS AND STRUCTURAL SYNERGY

As things stand in the world of structural analysis, it is up to the symphony orchestrated by diverse loads to take center stage. The purpose of this section is to explore the intricate choreography of load combinations on the access bridge, where gravitational, vehicular, and environmental forces are integrated to define the structural equilibrium and capacity of the bridge. As a result of these load combinations, the bridge is able to withstand a spectrum of challenges because of the scientific rigor that underpins its capability to withstand them.

8.1 Load Combinations for Serviceability and Ultimate States

Throughout the model, the canvas is unfurled with meticulous precision, capturing all the nuances of the various load scenarios that can arise. The combination of loads acts as a brush stroke, panning a comprehensive picture of the response of the bridge to the different forces that affect it under different conditions. Table 2 illustrates the load combinations that challenge bridge capacity while maintaining operational stability. This is in the symphony of serviceability, in which structure functional integrity has priority. For the ultimate state, where the forces imposed to cross the thresholds of capacity, Table 3 provides load combinations designed to simulate extreme scenarios in order to evaluate the bridge's structural resilience under extreme conditions. It is at the intersection of vehicular, environmental, and seismic loads that the strength of the bridge is demonstrated, as well as its ability to withstand and safeguard its occupants from harm.

Table 2. Load Combinations for Access Bridge Loading in Serviceability State.

Load Combination	Dead	Pipe	Truck 1	Truck 2	Truck 3	Truck 4	Truck 5	Truck 6	EQ_x	EQ_y
ASD1	1	1	-	-	-	-	-	-	-	-
ASD2	1	1	1.23	-	-	-	-	-	-	-
ASD3	1	1	-	1.23	-	-	-	-	-	-
ASD4	1	1	-	-	1.23	-	-	-	-	-
ASD5	1	1	-	-	-	1.23	-	-	-	-
ASD6	1	1	-	-	-	-	1.23	-	-	-
ASD7	1	1	-	-	-	-	-	1.23	-	-
ASD8	1	1	-	-	-	-	-	-	1	0.3
ASD7	1	1	-	-	-	-	-	-	0.3	1

8.2 Dynamic Considerations in Load Combinations

It goes without saying that seismic forces play a pivotal role in the symphony of load combinations that occur when earthquakes occur. The resulting seismic loads, imparted in both the X and Y directions, are accompanied by an accidental eccentricity in the orthogonal direction, which is a testimony to the dynamic nature of seismic interactions. We have further nuanced the interaction between the earthquake forces by taking into account 30% of the force exerted in an orthogonal direction in order to create a more comprehensive analysis of the bridge's response to seismic events.

9. ANALYSIS RESULTS AND STRUCTURAL RESPONSE

An intricate tapestry of deformations and internal forces make up the bridge's structural response to this intricate orchestration of forces that manifest themselves as a nexus of numerical values. There is a numeric manifestation of the bridge's ability to withstand and adapt to seismic forces contained in its maximum lateral displacement resulting from earthquake loading on the bridge. This is a numeric expression of the bridge's ability to withstand and adapt to earthquake loading. The piles emerge as architectural pillars of support, bearing the brunt of the loads with resolute resilience as a result of the labyrinth of analysis and its complexities. It is evident from Tables 4 and 5 that the maximum bending moments, shear forces, and axial forces that will be applied to the piles in the event of serviceability and ultimate loads are shown in order to provide a better understanding of those forces. According to Figure 6, the allocation of numbers to these structural components mirrors the intricate anatomy of the bridge, revealing the bridge's unity in diversity in spite of its many components.

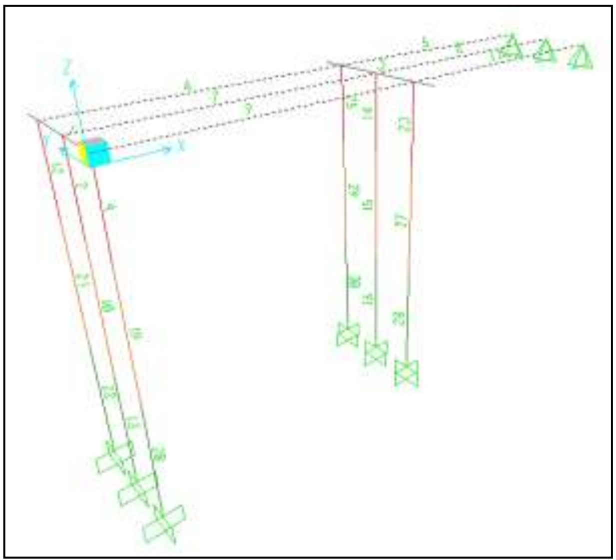

Figure 6. Identification of Structural Components in the Access Bridge.

Table 4. Flexural Anchor Values and Axial Force in Piles under Service Loads in X Direction.

	Value	Frame	Station	Output Case
M3 (Ton.m)	147/95	38	1/4	ASD8
M2 (Ton.m)	-89/38	30	5/51	ASD9
P (Ton)	-126/54	30	5/51	ASD9

Table 5. Values of Bending Moments and Axial Forces in Piles under Ultimate Loads.

	Value	Frame	Station	Output Case
M3	207/13	38	1/4	USD8
M2	-124/70	30	5/51	USD9
P	-178/44	28	5/51	USD5

The piles themselves, which have the capacity to carry a great deal of weight, are built from steel pipes with precise dimensions that have been forged. Steel's elastic modulus and specific weight, both intrinsic to the material's behavior, are intertwined with structural analysis to determine the piles' ability to survive. By controlling pile behavior against applied loads, SAP2000 emerges as a sentinel, ensuring structural stability and confirming that the bridge is capable of not only meeting but also surpassing the demands of engineering standards through its method of detecting structural instability. As a result of these analyses, a tapestry of pile stress ratios can be seen in Figure 7, which visually represents the findings.

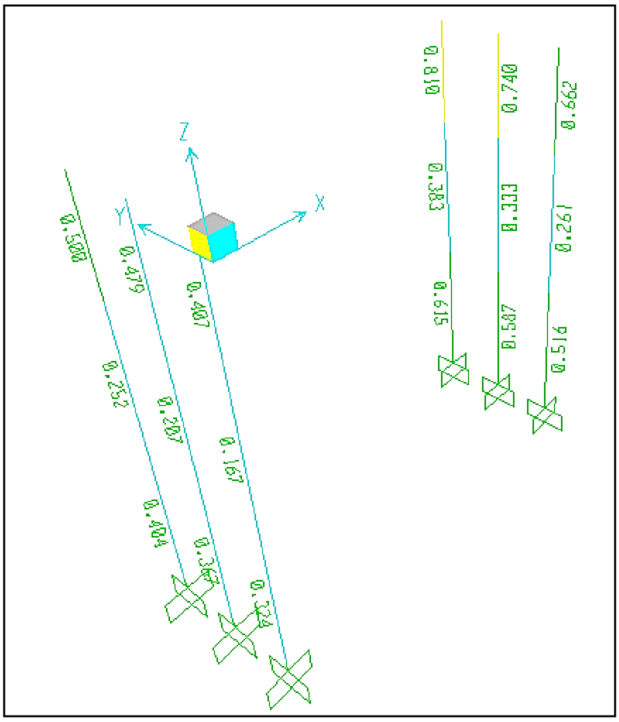

Figure 7. Pile Stress Ratios.

As an example of such a graph, which serves as an echo of complex mathematical calculations, this graph serves to demonstrate that piles are capable of bearing loads while maintaining structural equilibrium, no matter what the load will be. Unlike other graphs that provide a quick overview of the bridge's structural narrative, this graph provides a deeper look at the bridge's resilience and scientific rigor at each point on the graph. Upon digging deeper into the paper's depths, we come to a point when the bridge's architectural narrative reaches its denouement in the realm of conclusions, where the intersection of analysis and design is used to create an architectural triumph that resonates with scientific excellence.

10. CONCLUSION

The comprehensive analysis of the structural integrity of the new access bridge serving the new oil terminal in Bandar Anzali has come to highly favorable conclusions with regard to the structural integrity of the bridge. It is evident from a thorough examination of the stress ratios borne by all the piles of the structure that they all adhere steadfastly to the permissible parameters, proving the stability and adequacy of the structural framework. The investigation further indicates that if an earthquake were to occur, the maximum deflections experienced by the structure would be contained within a remarkably restricted range of deflections if the structure were to experience an earthquake. Particularly, these displacements can be quantified at just 4.6 cm on the X-axis and 1.4 cm on the Y-axis in the direction of displacement. The presence of such restrained deviations highlights the inherent resilience of the bridge in enduring seismic perturbations without affecting its operational stability as a result of the perturbations.

Although pile penetration depths are a pivotal issue, it remains prudent to address the issue with meticulous consideration, given the complexity of structural dynamics that are involved. It is important to recognize that since piles are relatively few, diligent scrutiny is required to determine the optimal penetration depths required to accommodate the gamut of tensile and compressive forces that may manifest within diverse loading scenarios. I would like to emphasize that it is imperative to emphasize that this determination will play a pivotal role in upholding the equilibrium and durability of the bridge under the complex interplay of forces that are at play within the structure. Taking a good look at the axial forces that are derived from the analysis, it is noteworthy that a coherent pattern emerges across all loading combinations as a result of the analytical assessment. All pile elements have axial forces aligned in a compressive direction such that no tensile forces will be generated within the pile elements due to the alignment of the axial forces. This cohesive response of the bridge is an indication of the structural stability of the bridge and the strength of the load-bearing capacity of its structure, enhancing a sense of confidence in the bridge's performance across a broad spectrum of operational scenarios. A culmination of this analytical exploration not only underscores the structural resilience and viability of the access bridge designed for the new oil terminal in Bandar Anzali, but it also serves as an exemplary example of how to combine scientific insight with engineering innovation to create a bridge that is structurally sound and viable. Beyond the immediate context in which this study was conducted, this study reveals valuable insights into the delicate balancing act required to determine how to fully integrate structural design with seismic considerations and material forces to achieve harmony. The maritime infrastructure faces an ever-evolving landscape of challenges, which is why this study stands out as a beacon, illuminating the path toward engineering solutions that are robust, adaptable, and scientifically informed.

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