Load Rating Evaluation by Finite Element Analysis: A Basis for Load Posting Structurally Deficient Bridges along National Roads in the Ilocos Region

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Abstract: - This study evaluated the load rating by finite element analysis of the structurally deficient bridges along national roads in the Ilocos Region as a basis for their load postings. Also, it aimed to develop a general procedure for load rating bridges as a standardized methodology for load rating bridges. The study is a descriptive-evaluative type of research, and data were gathered through reports, plans, field surveys, and field inspections. Two (2) structurally deficient bridges were evaluated, and an additional structurally adequate bridge was also evaluated as a means of calibrating the finite element method used in this study. Bridges were then analyzed through the MIDAS Civil software and aided with MS Excel to compute their load ratings. It was found that the load rating evaluation of the bridge through finite element analysis will yield higher load ratings than the simple approximate method (strip method). The formulated general procedure can be used as a standardized methodology for the load rating of bridges. It presented a systematic methodology that can be adopted for load rating bridges. The parts of the proposed general procedure are 1) bridge characterization, 2) bridge database, 3) field survey and inspection, and 4) bridge load rating. This provides a clear path that offers a step-by-step process and can be implemented for bridges that do not have existing as-built plans.

Key-Words: - bridge, live load capacity, load rating, load posting, finite element analysis, MIDAS Civil.

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1 Introduction

1.1 Background of the Study

For a nation to work effectively and efficiently, it requires many factors to meet its demands and needs. Infrastructures, notably road and bridge networks, can support these elements and hence play a significant role in society. They create a network of product and service transportation that is essential to a country's economy, [1]. Transportation holds an important responsibility for the economic growth of each nation and the safety of its users, [2]. Bridges are critical components of any transportation network because of their strategic placement and the severe repercussions when they collapse or when their capacity is impaired, [3]. Filipinos mostly depend on road and bridge networks to transport products and services to and from one location, [4]. Stated in a report that road transport was the main form of transport in the Philippines, comprising 47% of national freight transport and 78% of passenger transport.

Bridges in the Philippines are vulnerable to collapse during natural catastrophes. Most bridges in the Philippines do not pose any significant problems when used regularly; however, drivers should be aware that they are inadequately signed and lack load limitations. In some cases, bridges may have a capacity less than the regular traffic load of the road, and as a result, occasionally collapse. However, the Department of Public Works and Highways (DPWH) pointed out that this usually only occurs when transporters overload their vehicles. [5]. Bridges are prone to several defects over their service life, [6]. Due care must be given to them because bridges are aging, and a bridge failure or collapse might result in significant loss of life, property, environment, and economy, [7]. In line with this, the DPWH annually conducts condition inspections to assess and rate the condition of the structure. Bridges that are rated as poor and bad are those that may have major defects that affect the performance, stability, and structural integrity of the bridge, [8]. These bridges, rated as poor or bad, are classified as structurally deficient bridges, [9].

[10] Stated that various factors, including age, environment, and traffic, have been recognized as direct causes of bridge components and element deterioration. Repairs will be more costly if the bridges deteriorate due to aging, fatigue, loading, weather conditions, natural disasters, and other factors, [11].

A study of the evaluation of major bridges in Cagayan [12] Found that environmental variables and fatigue were the leading causes of bridge defects and damages. As a result, it was recommended that vehicles traversing these bridges be strictly monitored to ensure that no vehicle passes that exceeds the bridge capacity.

Taking into account the three variables mentioned above, with traffic regarded as controllable and manageable, load rating is recommended as a measure to prevent premature deterioration and damage of bridges along national roads in the Philippines. Load rating evaluation will serve as a follow-up to bridge condition inspection for structurally deficient bridges.

The load rating evaluation is a process of assessing the temporal condition of a structure and determining its safe load-carrying capacity, [13]. A bridge’s load rating generally aims to a) confirm the maximum load that the structure can support under acceptable safety conditions or b) increase the service load limit, [14]. With the increasing demands of freight traffic volumes, the aging factor of bridges, and damage from natural disasters, it is an important task to examine and re-evaluate the load rating of these bridges for their soundness and safe use.

As of October 15, 2020, there are a total of five hundred fifty-eight (558) bridges spanning a total length of 33,874 l.m. in the entire Ilocos Region. Four hundred and seventy (470) are concrete and eighty-eight (88) are steel. Some of these bridges were constructed even as early as 1911 based from the Road and Bridge Inventory reports of the DPWH. Of those, thirteen (13) were rated as poor and one (1) was rated as bad. Of these fourteen (14) structurally deficient bridges, twelve (12) bridges have already had or have ongoing bridge works relative to their condition as funded under various annual infrastructure programs of the DPWH. Two (2) of those, namely the Nilangoyan bridge in Rosario, La Union, and the Rodriguez bridge in Rosales, Pangasinan, were not funded for any bridge works relative to their condition rating, making them the subjects of this study. With this, there is a need for load rating for these bridges so they are still open to traffic and optimally functional. As of this date, no data shows that load rating was conducted for the structurally deficient bridges along national roads in the Ilocos Region.

This study aimed to evaluate the load rating of structurally deficient bridges along national roads in the Ilocos Region. Load rating will determine the safe live load that these bridges can carry and will be the basis for load posting these bridges with the main objective of preserving their soundness and safe use for continuous service to society, especially in the region. Also, it aimed to develop a general procedure for load rating bridges as a standardized methodology for load rating of bridges. The researcher seeks to pursue the study to serve also as a great help to society, particularly to the Department of Public Works and Highways (DPWH), which is of jurisdiction and responsible for the national roads and bridges, the motorists and commuters, and to Civil Engineering students, and future researchers.

1.2 Conceptual Framework

The study focused on evaluating the load rating of structurally deficient bridges along national roads in the Ilocos Region by finite element analysis as a basis for their load posting. It also aimed to develop a general procedure for load rating bridges as a standardized methodology for load rating of bridges.

The study's input included the bridge character properties, bridge geometric properties, bridge material strength properties, and bridge condition states.

The process done in this study involved bridge member demand forces and capacity calculation based on the bridge properties that were gathered, and load rating calculation based on capacity and demands. It also included the formulation of a general procedure for load rating of bridges.

The output contained the load posting of bridges and the recommended general procedure for load rating of bridges. The research paradigm in Appendix in Fig. 9 presents the Input-Process-Output model of the conceptual framework of the study.

1.3 Scope and Limitation

The study evaluated the load rating of those highway bridges along the national roads in the Ilocos Region that have undergone condition inspection and garnered a condition rating of poor or bad, classifying them as structurally deficient bridges for the evaluation year 2020.

The study also evaluated the load rating of one bridge along national roads in the Ilocos Region that is in good or fair condition as a means of calibrating the finite element method that was used in this study. The ratio of results from the approximate method and finite element method in evaluating this good or fair bridge was compared to the results that were yielded from evaluating structurally deficient bridges to validate the reliability of the method.

The study focused only on the bridge superstructure since this part of the bridge is the one mostly and directly subjected to external forces such as overloaded vehicles, increased dead load, vehicle collisions, and fatigue load; but careful attention was given to all elements of the substructure for evidence of instability that will affect its load-carrying capacity. All available information was checked to ensure that the substructure has at least the capacity of the lowest-rated superstructure member. If no information was available, the researcher judged the adequacy of the substructure based on observations of its condition and performance over time.

Loads considered for evaluation were limited to permanent (dead) loads, vehicular (live) loads, and earthquake loads.

The rating live load used in the basic rating equation was the MS-18 (HS20-44) truck or its equivalent lane loading under the DPWH Design Guidelines, as shown in Fig. 1.

The live load used in the rating equation for posting considerations was any of the typical legal loads shown in Fig. 2. For spans over 60 meters in length, the selected legal load shall be spaced with 9 meters of clear distance between vehicles to simulate a train of vehicles in one lane, and a single-vehicle load should be applied in the adjacent lane(s).

An attempt to consider this load for load rating will be made contrary to what the DPWH states. [15], recommends that this load shall be neglected. With the increasing congestion of traffic, the likelihood of significant live load being on a bridge during the design earthquake is much more likely today, [16].

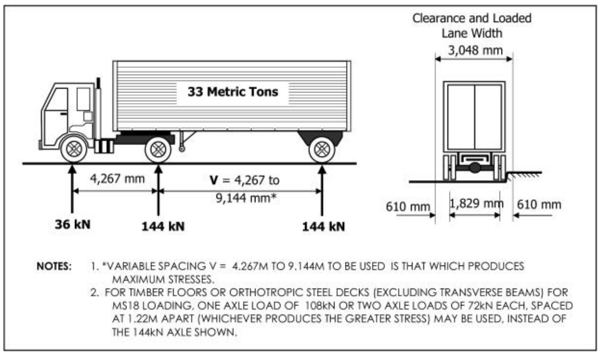

Fig. 1: Rating Live Load (MS18 Vehicle Loading)

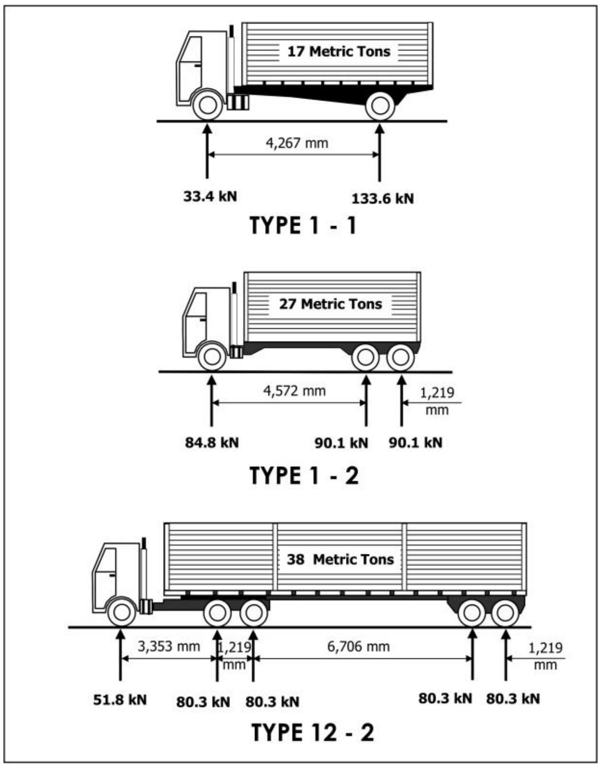

Fig. 2: Typical Legal Loads Used for Load Posting

Structural analysis of subject bridges was conducted by two (2) methods: the approximate method (strip method), the method of analysis recommended by the DPWH, and the finite element method, a more refined method of analysis.

Currently, adopting the load rating evaluation approach suggested by the American Association of State Highway and Transportation Officials (AASHTO) Manual for Bridge Evaluation, which is also the core basis of the DPWH Manual for Load Rating of Bridges, using the approximate method (strip method), would underestimate the actual bridge load-carrying capacity. The analysis of an assemblage of finite elements that are interconnected at a finite number of nodal points shows that the finite element model gives more economical results, [17]. Bridges estimated to be under capacity using AASHTO approximate methods were still sufficient based on finite element analysis, [18]. It was also found that bridges exhibited higher load-carrying capacity upon evaluation by finite element analysis than the estimated initial restrictive loads posted, which were based on the simplified approximate method, [19]. [20] presented the theory of limit design, which states that the capacity load that a redundant structure can support is not limited to the load that stresses one part to the elastic limit; rather, the structure's capacity load is reached once all of its members, corresponding to the number of redundant members, have all reached their elastic limit strength.

Load rating was performed at the inventory rating and operating rating levels only. The inventory load level approximates the design load level under normal service conditions, [21]. Load rating based on the operating rating level shows the absolute maximum allowed live load that the bridge may safely carry, [22].

2 Methodology

The study used a descriptive-evaluative research design utilizing quantitative research approaches since the result of the study will assess the load rating of highway bridges along national roads in the Ilocos Region.

[23] defined the descriptive-evaluative research design as a research design that gathers information from a present existing condition. This design is used to describe the nature of a situation as it exists at the time of study and to explore the cause of a particular phenomenon. This research design aims to obtain an accurate profile of the current situation. With this research type, it is essential that the researcher already has a clear view or picture of the phenomena being investigated before the data collection procedure is carried out. Under this research design, the case study method will be used to closely examine the data of the subject, [24].

2.1 Population and Locale of the Study

The Ilocos Region, or Region 1, is divided into ten (10) District Engineering Offices (DEOs) by the DPWH as follows: Ilocos Norte 1st and 2nd DEO, Ilocos Sur 1st and 2nd DEO, La Union 1st and 2nd DEO, and Pangasinan 1st, 2nd, 3rd, and 4th DEO.

The subjects of this study were the Nilangoyan Bridge in the La Union 2nd DEO and the Rodriguez Bridge in the Pangasinan 3rd DEO; these two (2) bridges were both in poor condition. Also, another subject of this study was the Bayugao Bridge in Ilocos Sur 2nd DEO, which is a newly constructed widening bridge, as a means of calibrating the finite element method that was used in this study. Pertinent data relative to the three (3) subject bridges were obtained from the DPWH Bridge Management System (BMS) through the DPWH Regional Office 1 BMS coordinator and described as follows.

Nilangoyan Bridge, with bridge ID of B02628LZ, is situated along Manila North Road, Brgy. Cataguintingan, Rosario, La Union, as shown in Fig. 3.

Rodriguez Bridge, with bridge ID of B00749LZ, is situated along Pangasinan-Nueva Ecija Road, Brgy. Bakit-Bakit, Rosales, Pangasinan, as shown in Fig. 4.

Bayugao Bridge, with bridge ID of B00609LZ, is situated along Manila North Road, Brgy. Bayugao, Sta. Cruz, Ilocos Sur, as shown in Fig. 5.

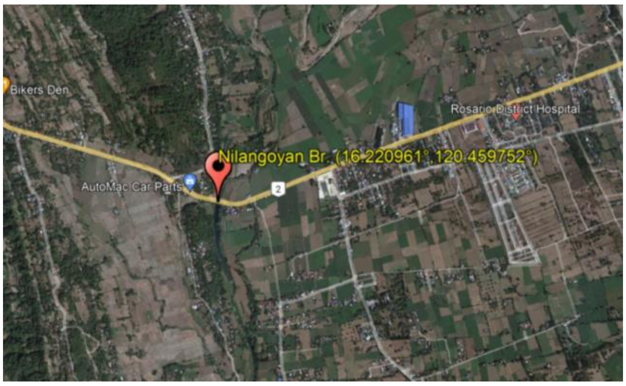

Fig. 3: Location Map of Nilangoyan Bridge

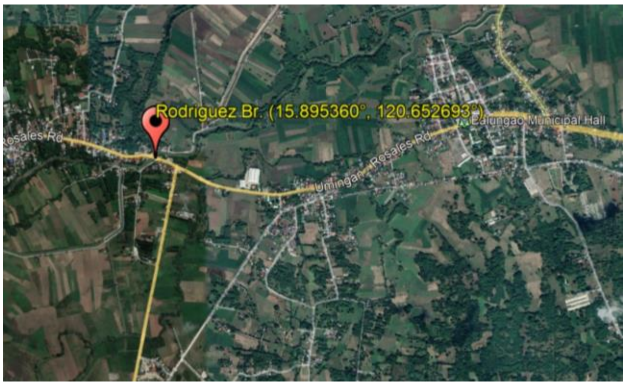

Fig. 4: Location Map of Rodriguez Bridge

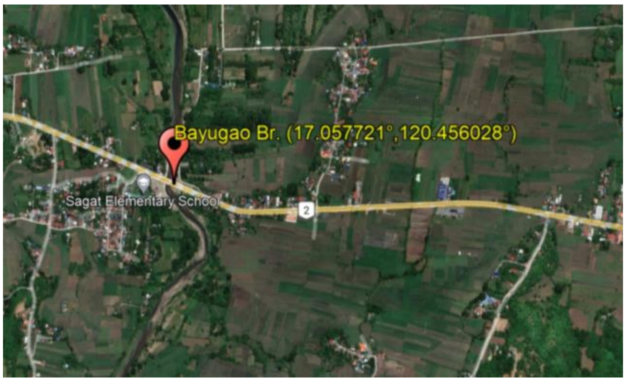

Fig. 5: Location Map of Bayugao Bridge

2.2 Data Gathering Procedure

Data gathering through research and the collection of existing data was employed to secure relevant information concerning the subject bridges.

The bridge character properties and other critical information required for load rating were determined through the DPWH Bridge Management System reports with the aid of the BMS Coordinator from the Regional Office 1 or the District Office of concern. Current and past DPWH-BMS reports were also examined to assess the bridge condition states.

A survey of the subject bridge's as-built plans and other comparable bridge plans based on bridge type and year of construction was also conducted to identify for consideration bridge geometric properties and bridge material strength properties. These plans were retrieved from the DPWH Regional Office 1 or the District Office of concern.

Gathering data through field surveys and inspection of the bridges with the aid of surveying, measuring, and conducting non-destructive testing (NDT) was employed to determine the bridge members' geometric properties, current material strength properties, current condition states, and other relevant information not found on reports. Surveying instruments and NDT equipment were borrowed from the DPWH Regional Office 1.

2.2.1 Bridge Characterization

Bridges were classified according to the bridge character properties determined. Other critical information required for load rating was listed and summarized.

2.2.1.1 Bridge Classification

[25] classified constructed bridges in the Philippines according to various factors on bridges' constructability.

A bridge can be classified according to its span type: 1) simple spans, 2) continuous spans, and 3) cantilever bridges.

A bridge can also be classified according to the materials used for the main structural members: 1) timber bridge, 2) concrete bridge (reinforced and prestressed), and 3) steel bridge (I-beam, plate girder, truss, and box girder), [26].

A bridge can also be classified according to its form: 1) Arch bridge, 2) beam bridge, 3) truss bridge, 3) cantilever bridge, 4) suspension bridge, 5) cable-stayed bridge, 6) roving bridge, [27].

2.2.2 Bridge Database

A database with information about bridge character properties, geometric properties, material strength properties, and condition states, which were gathered from DPWH BMS reports, bridge as-built plans, and other comparable bridge plans, was created.

2.2.3 Field Survey and Inspection

The findings on the information and condition of the bridge outlined in the reports and plans were corroborated by the field survey and inspection. Data from previous steps was taken into consideration to have a detailed representation of the bridge. Bridge defects and their severity were checked and recorded accordingly, and the condition of the structure was accounted for in the load rating process. Updated as-built drawings of the bridge were created based on the bridge information collected from the database and field measurements and served as the working model for the structural analysis.

Material properties for bridge components were based on material properties specified in plans or design drawings or from the results of conducting the non-destructive testing. When no plans were available or they did not specify material properties, the utilization of available information was used. The year when the bridge was constructed can be used as a basis. The AASHTO suggests the following material properties when the actual grade of materials is unknown as presented in Table 1.

Table 1. Material Properties when Actual Grade is Unknown

Material	Year of Const'n	Fy or F'c or Fpu (MPa)	Allowable Stress Ratings	
			I.L. (MPa)	O.L. (MPa)
Structural Steel Bending (Compression/ Tension)	Before 1905	179.3	96.5	134.4
	1905 to 1936	206.8	110.3	155.1
	1936 to 1963	227.5	124.1	168.9
	After 1963	248.2	137.9	186.2
Structural Steel Web Shear	Before 1905	79.3	58.6	79.3
	1905 to 1936	206.8	65.5	93.1
	1936 to 1963	227.5	75.8	103.4
	After 1963	248.2	82.7	110.3
Reinforcing Steel Tension	Before 1954	227.5	124.1	172.4
	After 1954	275.8	137.9	193.1
	Grade 40	275.8	137.9	193.1
	Grade 50	344.7	137.9	224.1
	Grade 60	413.7	165.5	248.2
Concrete Bending	Before 1959	17.2	6.9	10.3
	After 1959	20.7	8.3	13.1
	1977 to 1981	27.6*	11.0*	16.5*
	After 1981	31.0*	12.4*	18.6*

2.2.4 Bridge Load Rating

2.2.4.1 Structural Modelling and Analysis

Using the updated as-built drawings of the bridge, the subject bridges were modeled and analyzed in the MIDAS Civil program to determine the member demand forces and capacity for shear, moment, axial, or any critical failure mode, depending on the bridge structural system and condition of bridge members. Finite element modeling in general was used to accurately capture the overall behavior of the bridge as a whole system, especially since earthquake load was considered in the study.

MIDAS Civil. This is a finite element analysis software developed by MIDASoft and used for bridge analysis and design. This combines the powerful pre- and post-processing features with an extremely fast solver, which makes bridge modeling and analysis simple, quick, and effective, [28].

2.2.4.2 Load Rating Calculation

Utilizing the results, the demand forces, and capacity from the structural modeling and analysis by the finite element method, rating factors for critical members were computed. This rating factor was the ratio of the available capacity of the member and the live load demand. The rating factor will then be used to determine the load rating of the bridge member in metric tons by multiplying this factor by the weight of the nominal truck used in determining the live load effect. The calculations of the rating factor and load rating will be done with the aid of Microsoft Excel.

Microsoft Excel. Microsoft (MS) Excel is a spreadsheet software program that organizes numbers and data with the aid of formulas and functions. It has a vast database of formulas to answer engineering needs that can be utilized to perform various engineering operations.

Load postings of the subject bridges were based on the calculated load ratings of the bridges and were the lowest ratings at the inventory level.

Based on the previously presented steps for the treatment of data, a general procedure for load rating of bridges was formulated. While load rating can be implemented for many existing, especially newly constructed bridges, some can't be easily evaluated due to poor documentation and the absence of plans, especially old bridges. The presented general procedure in Fig. 6 will be of great help in gathering critical information needed for the analysis and evaluation of bridges in an organized and rational manner. This had four major parts, namely: 1) bridge characterization, 2) bridge database, 3) field survey and inspection, and 4) bridge load rating.

Fig. 6: Proposed General Procedure for Bridge Load Rating

3 Results and Discussions

By following the proposed general procedure for bridge load rating, data were gathered systematically and were presented accordingly.

3.1 Bridge Characterization

Bridge characterization contains properties that were used to classify the bridges. This involved the identification of the bridges' span type, materials used in construction, form, and year of construction. Bridge information for all bridges is different from each bridge, and bridge characterization will help to summarize this critical information that would be useful in the conduct of structural evaluation of the bridge structure. Bridge character properties presented are under this part of the procedure.

After conducting a characterization of both bridges, it was found that the critical information needed in the bridge load rating process of both bridges is geometric properties, and material properties, among other parameters. A list of variables containing the critical bridge information for the two types of subject bridges is summarized in Table 2.

The presented bridge variables were deemed to be necessary as the working inputs for the load rating process. These variables can also be used for other bridges of the same type for the load rating process.

Table 2. Bridge Variables

Steel I-Girder Bridge (Nilangoyan Br.)	Reinf. Concrete Bridge (Rodriguez Br. & Bayugao Br.)
▪ Bridge Type	▪ Bridge Type
▪ Year of Construction	▪ Year of Construction
▪ Span Type	▪ Span Type
▪ Bridge Length	▪ Bridge Length
▪ Bridge Width	▪ Bridge Width
▪ Girder Section Properties	▪ Girder Section Properties
▪ Girder Spacing	▪ Girder Spacing
▪ Concrete Elastic Modulus	▪ Concrete Elastic Modulus
▪ Steel Elastic Modulus	▪ Steel Elastic Modulus
▪ Number of Girders	▪ Number of Girders
▪ Number of Spans	▪ Number of Spans
▪ Span Length	▪ Reinf. Sectional Area
▪ Strength of Steel Section	▪ Span Length
▪ Thickness of Asphalt	▪ Strength of Concrete
▪ Thickness of Slab	▪ Strength of Steel Reinforcement
▪ Asphalt Unit Weight	▪ Thickness of Asphalt
▪ Concrete Unit Weight	▪ Thickness of Slab
▪ Steel Unit Weight	▪ Asphalt Unit Weight
▪ Main Member Defects & Severity	▪ Concrete Unit Weight
	▪ Steel Unit Weight Main Member Defects & Severity

3.2 Bridge Database

Past reports of all bridges were collected. The goal was to discern if there was any valuable information that could be found in these reports that could provide insight regarding the variables shown in Table 2 or any other relevant information. Inspection reports from the year 2019 up to 2022 were gathered from the DPWH through the Bridge Management System Regional Coordinator and examined.

According to the reports, both bridges were in poor condition from 2019 up to 2022, as presented in Table 3. No rehabilitation, retrofitting, or any other related bridge works were initiated to address the condition rating of the bridges.

Table 3. Bridge Overall Condition

Year of Report	Overall Condition	
	Nilangoyan Bridge	*Rodriguez Bridge*
2019	Poor	Poor
2020	Poor	Poor
2021	Poor	Poor
2022	Poor	Poor

The DPWH rated the Nilangoyan bridge as poor, corresponding to defects and severity as presented in Appendix in Table 15 and Table 16. It can be noted that since the bridge's main structural part is a steel I-Girder, steel corrosion will be one of the most common defects that can be found. Corrosion can be considered as extractive metallurgy but in reverse. This means that exposure to oxygen and water reverses the process of changing raw ore into metal, [29]. All other structure elements were constructed with reinforced concrete, and the most prevailing defects among these bridge elements are cracks and spalling.

The DPWH rated the Rodriguez bridge also as poor, corresponding to the defects and severity as presented in Appendix in Table 17 and Table 18 Of the appendix. It can be noted that since the majority of the structure elements are constructed with reinforced concrete, the most prevailing defects among bridge elements are also cracks and spalling. Concrete cracks, particularly in the bridge's main elements, could be interpreted as indicators of the degree of corrosion damage in the steel reinforcements. The greater width of the crack opening may correspond to the later stages of the start of corrosion in the member, [30].

As part of the procedure, in the absence of the bridge plans, other comparable plans were gathered from the DPWH. These similar plans were the standard plans that the DPWH is adopting closely to the year of construction of the bridges of concern that do not have available plans. The standard plans were almost similar to the on-site geometric properties of the bridges, and thus, can be adopted. Some of the plans also had design data notes that specified the design stresses for concrete, reinforcing steel, and structural steel, together with the design live load as MS-18 truck loading, following the standard specification for highway bridges, [31]. The Allowable Stress Design (ASD) and Load Factor Design (LFD) were the design philosophies corresponding to that era.

3.3 Field Survey and Inspection

A field survey and inspection were conducted to quantify and supplement the additional information needed to further characterize the bridge structure and to complete the bridge database.

Non-destructive testing was conducted on both bridges to determine in-situ properties. Test results for the Nilangoyan bridge are shown in Table 4. The paint thickness test revealed the existing paint coating thickness of the steel I-girders and is almost the same at all test locations, meaning that steel corrosion for the members is not severe, and based on reports, corrosion is rated as fair. Coatings can protect steel for decades; this is true in Nilangoyan, where paint served its purpose to protect the steel from severe corrosion, [32]. The metal thickness test also revealed the almost uniformity of the flange and web dimensions throughout the member, meaning that there were no evident significant section losses.

Table 4. Nilangoyan Bridge NDT Results

Test Conducted	Member Location		Readings
For Steel Attributes			
Paint Thickness Test	Girder:	Upper Flange	331.80 µm
		Web	281.67 µm
		Lower Flange	347.40 µm
Metal Thickness Test	Girder:	Upper Flange	19.89 mm
		Web	29.81 mm
		Lower Flange	19.93 mm

Table 5 shows the results of non-destructive testing for the Rodriguez bridge. A rebound hammer test was performed to determine the in-situ compressive strength of the concrete that was used for the girder capacity calculation. In general, rebound hammer tests underestimate the actual compressive strength of concrete, and thus, can be considered to be conservative and can be fairly reliable in the conclusion of safe continued use of in-situ concrete, [33]. UPV test revealed no significant delamination of concrete, and on the other hand, also revealed the depth of shear cracks, which is already more than half of the girder web width. The rebar detection test also confirmed that the reinforcement configuration at the site is the same as what was adopted from the previously found similar plan.

Table 5. Rodriguez Bridge NDT Results

Test Conducted	Member Location	Readings
For Concrete Attributes		
Rebound Hammer Test	Girder :	20.57 MPa concrete compressive strength
Ultrasonic Pulse Velocity (UPV) Test	Girder :	265 mm depth of shear cracks
Rebar Detection Test	Girder :	36mm ø main bars; and 12mm ø stirrups spaced at 100mm (near supports)

Table 6 and Table 7 show the database of Nilangoyan and Rodriguez Bridge, respectively, containing the information gathered from the reports, plans, and any other materials from the DPWH. The bridge databases were further supplemented and completed with data that came from the results of conducting field surveys and inspections. Results from the non-destructive testing and on-site measurement gathering were all included and considered in the following databases created.

Table 8 shows the database of the Bayugao Bridge containing information gathered from the plans of the DPWH. Field survey and inspection were still conducted, and it was confirmed that all data that were extracted from the available plans matched with those on site.

The field inspection did not reveal any information that does not conform to what the reports already noted. From the preceding, drawings of all three (3) bridges, shown in Appendix in Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18, Figure 19, Figure 20 and Figure 21 were created using the information summarized from the bridge database, and field survey, and the inspection. The drawings included a plan view, profile view, typical cross-section view, and typical girder section view.

Table 6. Nilangoyan Bridge Database

Property	Bridge Variables	Values
Bridge Character Properties	Bridge ID:	B02628LZ
	Bridge Type:	Steel I-Girder
	Year of Construction:	1950
	Span Type:	Simple Span
Bridge Geometric Properties	Bridge Length:	56.00 m
	Span Lengths:	17.5m–21m–17.5m
	Bridge Width:	16.83 m
	Girder Section Properties:	270 x 20mm Upper Flange, 760 x 30mm Web, 270 x 20mm Lower Flange
	Girder Spacing:	1.73 m
	Number of Girders:	5
	Number of Spans:	3
	Thickness of Asphalt:	50 mm
	Thickness of Slab:	200 mm
Bridge Material Properties and Condition	Concrete Elastic Modulus:	19,492.255 MPa
	Steel Elastic Modulus:	200,000.00 MPa
	Strength of Steel Section:	227.50 MPa
	Unit Weight of Asphalt:	22.00 kN/m^3
	Unit Weight of Concrete:	24.00 kN/m^3
	Unit Weight of Steel:	77.00 kN/m^3
	Overall Condition:	Poor
	Main Member Defects & Severity:	Steel Corrosion / Fair

Table 7. Rodriguez Bridge Database

Property	Bridge Variables	Values
Bridge Character Properties	Bridge ID:	B00749LZ
	Bridge Type:	Reinf. Conc. Girder
	Year of Construction:	1990
	Span Type:	Simple Span
Bridge Geometric Properties	Bridge Length:	57.91 m
	Span Lengths:	15m–15m–15m–12m
	Bridge Width:	20.00 m
	Girder Section Properties:	1020 x 500mm
	Girder Spacing:	2.4 m
	Number of Girders:	4
	Number of Spans:	4
	Thickness of Asphalt:	50 mm
	Thickness of Slab:	180 mm
Bridge Material Properties and Condition States	Concrete Elastic Modulus:	21,316.456 MPa
	Steel Elastic Modulus:	200,000.00 MPa
	Reinf. Sectional Area:	12,215 mm^2 Main Bar, 113 mm^2 Stirrups
	Strength of Concrete:	20.57 MPa
	Strength of Steel Reinf.:	275.80 MPa
	Unit Weight of Asphalt:	22.00 kN/m^3
	Unit Weight of Concrete:	24.00 kN/m^3
	Unit Weight of Steel:	77.00 kN/m^3
	Overall Condition:	Poor
	Main Member Defects & Severity:	265mm Depth of Cracks / Bad

Table 8. Bayugao Bridge Database

Property	Bridge Variables	Values
Bridge Character Properties	Bridge ID:	B00609LZ
	Bridge Type:	Reinf. Conc. Girder
	Year of Construction:	2021
	Span Type:	Continuous Span
Bridge Geometric Properties	Bridge Length:	91.50 m
	Span Lengths:	15m–15m–15m–15m-15m–15m
	Bridge Width:	17.74 m
	Girder Section Properties:	1,100 x 400mm
	Girder Spacing:	1.723 m
	Number of Girders:	3
	Number of Spans:	6
	Thickness of Asphalt:	-
	Thickness of Slab:	200 mm
Bridge Material Properties and Condition States	Concrete Elastic Modulus:	24,870.062 MPa
	Steel Elastic Modulus:	200,000.00 MPa
	Reinf. Sectional Area:	10,179 mm^2 Main Bar(Midspan); 10,453 mm^2 Main Bar(Support); 201 mm^2 Stirrups
	Strength of Concrete:	28 MPa
	Strength of Steel Reinf.:	414 MPa
	Unit Weight of Asphalt:	22.00 kN/m^3
	Unit Weight of Concrete:	24.00 kN/m^3

Unit Weight of Steel:	77.00 kN/m^3
Overall Condition:	Good
Main Member Defects & Severity:	No Significant Defects

3.4 Bridge Load Rating

Utilizing the furnished drawings of the three (3) bridges based on all gathered data, the bridges were modeled using the Midas Civil design software. The grillage model was utilized to further simulate the finite element in a more refined manner. All girders were interconnected at every one (1) meter by dummies to represent the rigid transverse connection and to take the structure as one assembly. The structural models and the corresponding result diagrams of the three (3) bridges are presented in Appendix in Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, Figure 28, Figure 29, Figure 30, Figure 31, Figure 32, Figure 33, Figure 34, Figure 35, Figure 36, Figure 37, Figure 38, Figure 39, Figure 40, Figure 41, Figure 42, Figure 43 and Figure 44.

The boundary conditions at the abutments were assumed as hinged to simulate the actual separation of the superstructure from the substructure and to determine the maximum demand forces acting on the girders. The values for demand shear and moment for each load case (dead load, live load, and earthquake load) were obtained for each girder of the assembly. The girder with the highest demand was considered for the load rating process, as this gave the lowest rating factor.

The calculation process to find the load rating values of the members was aided by Microsoft Excel. The capacity of the members depends upon the steel reinforcement and concrete area, structural steel area, and material strengths. These capacities were computed based on Allowable Stress Design (ASD) for capacities by allowable stresses, and from Load Factor Design (LFD) for ultimate capacities.

The girders were evaluated for their strength limit states, and Table 9 shows the controlling limit states for the three (3) bridges. These limiting states are the failure conditions of the member capacities relative to the demands from the structural modeling and analysis.

Table 9. Bridge Controlling Limit States

Bridge Name	Limit State
Nilangoyan Bridge	Flexure at Midspan
Rodriguez Bridge	Shear near Support
Bayugao Bridge	Flexure at Midspan

Bridge load rating was conducted after completing all the necessary data for modeling and analysis. Bridge load rating by finite element method, which was used in this study, was conducted on the Bayugao bridge as a means of calibrating the said method. Bayugao Bridge is a newly replaced bridge along Manila North Road and is rated as fair. The evaluation shows a higher load rating than the load rating, even at the inventory level only, and is shown in Table 10. This means that the results of load rating affirm that the bridge can carry the load rating vehicle as it should. This validates that the proposed method can be used for the load rating evaluation. Also, load rating by the approximate and finite element method without seismic load was conducted to further evaluate and calibrate the finite element method. The ratios of the finite element and approximate method results are also shown below.

Table 10. Bayugao Br. Load Rating

Rating Vehicle	Rating Level	Load Rating, tons			FEM-Approx. Ratio
		Approx. Method	*FEM (w/o Seismic)*	*FEM (w/ Seismic)*	
MS-18, 33 tons	I.L.	88	131	99	1.13
	O.L.	158	215	183	1.16

Also, load posting analysis was conducted on the Bayugao bridge based on the Finite Element Method and the results are shown in Table 11 together with the ratio of finite element and approximate method. Load postings were also greater than the typical legal load used for load posting. These typical legal loads were the actual loads posted on the said bridge, and the ratios were in the same range as the load rating results. This backs up the idea that the proposed method can be used for load rating evaluation.

Table 11. Bayugao Br. Load Posting by FEM

Posting Vehicles	Rating Level	Load Rating, tons		FEM-Approx. Ratio	Load Posting by FEM
		Approx.	*FEM*		
Type 1-1, 17 tons	I.L.	68	75	1.10	*17 tons*
	O.L.	122	138	1.13	
Type 1-2, 27 tons	I.L.	81	90	1.11	*27 tons*
	O.L.	145	167	1.15	
Type 12-2, 38 tons	I.L.	127	139	1.09	*38 tons*
	O.L.	229	257	1.12	

Table 12 shows the load rating evaluation results for the Nilangoyan Bridge and Rodriguez Bridge, respectively. It was conducted by two (2) methods, namely: 1) by the approximate method (strip method), the method of analysis recommended by the DPWH; and 2) by the finite element method, a more refined method of analysis. It can be noticed that the finite element method yields a higher load rating than the approximate method, for both bridges. This concept of the finite element method yielding higher load-carrying capacity than the traditional approximate method was previously proven by a study utilizing refined analysis to evaluate the load capacity of an existing steel plate girder swing span bridge, [34]. This hypothesis was also validated by a study on load rating of load-posted continuous steel girder bridges, where refined load rating factors for the bridge are significantly higher than the already posted limits, which were calculated through basic load rating analysis by the approximate approach, [35]. Also, for the finite element method, considering earthquakes in the analysis will still yield a higher load rating compared to the approximate method, but somewhat lower when earthquake load is omitted. It can be noticed that at the operating level, the approximate method already yielded a load rating that is significantly lower than the rating vehicle. However, conducting a finite element analysis negates this idea since the results yielded a higher absolute maximum permissible load than the rating vehicle. This means that even an overloaded but less frequent vehicle of the same type can still safely pass by the bridge without compromising its integrity. Also, ratios of the finite element and approximate method results were shown below, which is close to the ranges of the ratios of results from the load rating of the Bayugao bridge.

Table 12. Bridge Load Rating

Rating Vehicle	Rating Level	Load Rating, tons			FEM-Approx. Ratio
		Approx. Method	*FEM (w/o Seismic)*	*FEM (w/ Seismic)*	
Nilangoyan Bridge					
MS-18, 33 tons	I.L.	11	16	13	1.18
	O.L.	30	42	39	1.30
Rodriguez Bridge					
MS-18, 33 tons	I.L.	22	30	25	1.14
	O.L.	37	50	44	1.19

Table 13 shows the posting loads for the Nilangoyan Bridge and Rodriguez Bridge, respectively, based on finite element analysis. Load limits computed were noticeably lower than that of the three (3) typical legal loads and thus shall be the loads to be posted for the bridges. It can also be observed that at operating levels, both bridges still have an absolute maximum permissible load higher than the posted vehicles, and thus can still accommodate less frequently passing overloaded vehicles of the same type. These loads computed at operating levels will be the basis for DPWH on issuing special permits to travel for vehicles of the same type that exceed the maximum allowable gross vehicle weight (GVW) as defined in the revised Implementing Rules and Regulations of the Republic Act No. 8794. Also, ratios of finite element and approximate method were shown below, and they were of the same range as the load rating results.

Table 13. Load Postings by Finite Element Method

Posting Vehicles	Rating Level	Load Rating, tons		FEM-Approx. Ratio	Load Posting by FEM
		Approx.	*FEM*		
Nilangoyan Bridge					
Type 1-1, 17 tons	I.L.	9.00	11.00	1.22	*11 tons*
	O.L.	25.00	33.00	1.32	
Type 1-2, 27 tons	I.L.	10.00	12.00	1.20	*12 tons*
	O.L.	28.00	36.00	1.29	
Type 12-2, 38 tons	I.L.	14.00	16.00	1.14	*16 tons*
	O.L.	37.00	49.00	1.32	
Rodriguez Bridge					
Type 1-1, 17 tons	I.L.	19.00	20.00	1.05	*17 tons*
	O.L.	32.00	35.00	1.09	
Type 1-2, 27 tons	I.L.	21.00	23.00	1.10	*23 tons*
	O.L.	36.00	41.00	1.14	
Type 12-2, 38 tons	I.L.	29.00	34.00	1.17	*34 tons*
	O.L.	5491.00	60.00	1.22	

The rating factor was then computed based on the computed capacity for live load divided by the live load demand corresponding to the controlling limit states. And lastly, the load rating was computed by multiplying the rating factor by the rating vehicle weight. Table 14 shows the load rating results and the load postings.

Figure 7 shows the load posting sign for Nilangoyan Bridge. Load limits for the three types of trucks are as follows: 11 metric tons for a 2-axle truck; 12 metric tons for a 3-axle truck; and 16 metric tons for a 5-axle truck.

Figure 8 shows the load posting sign for the Rodriguez Bridge. Load limits for the three types of trucks are as follows: 17 metric tons for a 2-axle truck; 23 metric tons for a 3-axle truck; and 34 metric tons for a 5-axle truck.

Table 14. Bridge Load Ratings and Postings

	Vehicle	Bayugao Bridge	Nilangoyan Bridge	Rodriguez Bridge
Load Rating	MS-18, 33 tons	33 tons	13 tons	26 tons
Load Posting	Type 1-1, 17 tons	17 tons	11 tons	17 tons
	Type 1-2, 27 tons	27 tons	12 tons	23 tons
	Type 12-2, 38 tons	38 tons	16 tons	34 tons

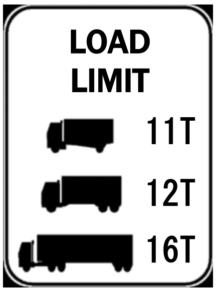

Fig. 7: Nilangoyan Bridge Load Posting Sign

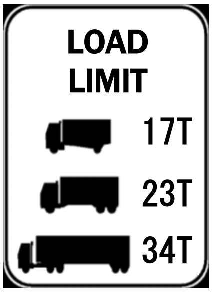

Fig. 8: Rodriguez Bridge Load Posting Sign

A flowchart was formulated as an output of the study, which was based on the findings. The load rating process in this study was generally guided by the general procedure, especially for steel I-girder bridges and reinforced concrete bridges. The flowchart is shown in Appendix in Figure 22.

The proposed general procedure was generally based on the experience of the researcher during the conduct of this study.

The parts of the proposed general procedure are: 1) Bridge Characterization, 2) Bridge Database, 3) Field Survey and Inspection, and 4) Bridge Load Rating.

General Objectives

The objectives of the general procedure for load rating bridges are:

1. To standardize the methodology for load rating bridges for the DPWH;
2. To provide the DPWH with a systematic methodology with clear specifics on the step-by-step process of load rating of bridges.

4 Conclusion

This study developed a general procedure for load rating bridges. The procedure has four major parts: (1) Bridge Characterization, (2) Bridge Database, (3) Field Survey and Inspection, and (4) Bridge Load Rating. The procedure was followed to come up with the load rating of the structurally deficient bridges.

The results of following this procedure were presented in the previous chapter. Based on the findings, conclusions were drawn accordingly.

To be able to evaluate the load rating or the current safe live load capacity of a bridge, the properties of the bridge need to be defined first as the fundamentals for the modeling and analysis. These properties vary from one bridge to the other, especially for different types based on materials used in construction.

Knowing the load ratings of structurally deficient bridges by the approximate technique and finite element approach is critical because it is the data used to evaluate firsthand the degree of structural soundness of the bridge to safely carry live loads. This determines whether the bridge needs to be load-posted for restrictive use or needs to be closed. The load ratings at this state serve as a screening process to identify bridges that should be load-rated for legal loads.

The load rating evaluation of bridges through the simpler approximate method (strip method), although attractive for its simplicity, could yield overly conservative bridge load ratings. Load rating evaluation through finite element analysis will yield higher bridge load ratings since this could better capture the actual bridge response.

Bridges that do not have sufficient capacity under the load rating by MS-18 vehicles were load-rated for legal loads to establish the need for load posting. Knowing the load posts for structurally deficient bridges comes with vital importance and it is the actual safe load capacity of the bridge corresponding to the legal loads which, nevertheless, are the type of vehicles frequently passing by the national roads.

The formulated general procedure can be used as a standardized methodology for the load rating of bridges. It presented a systematic methodology that can be adopted for load rating bridges. This provides a clear path that offers a step-by-step process and can be implemented for bridges that do not have existing as-built plans.

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Declaration of Generative AI and AI-assisted Technologies in the Writing Process

The author used QuillBot to improve the readability and language of the study. After this, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The author solely contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

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Conflict of Interest

The author has no conflicts of interest to declare.

APPENDIX

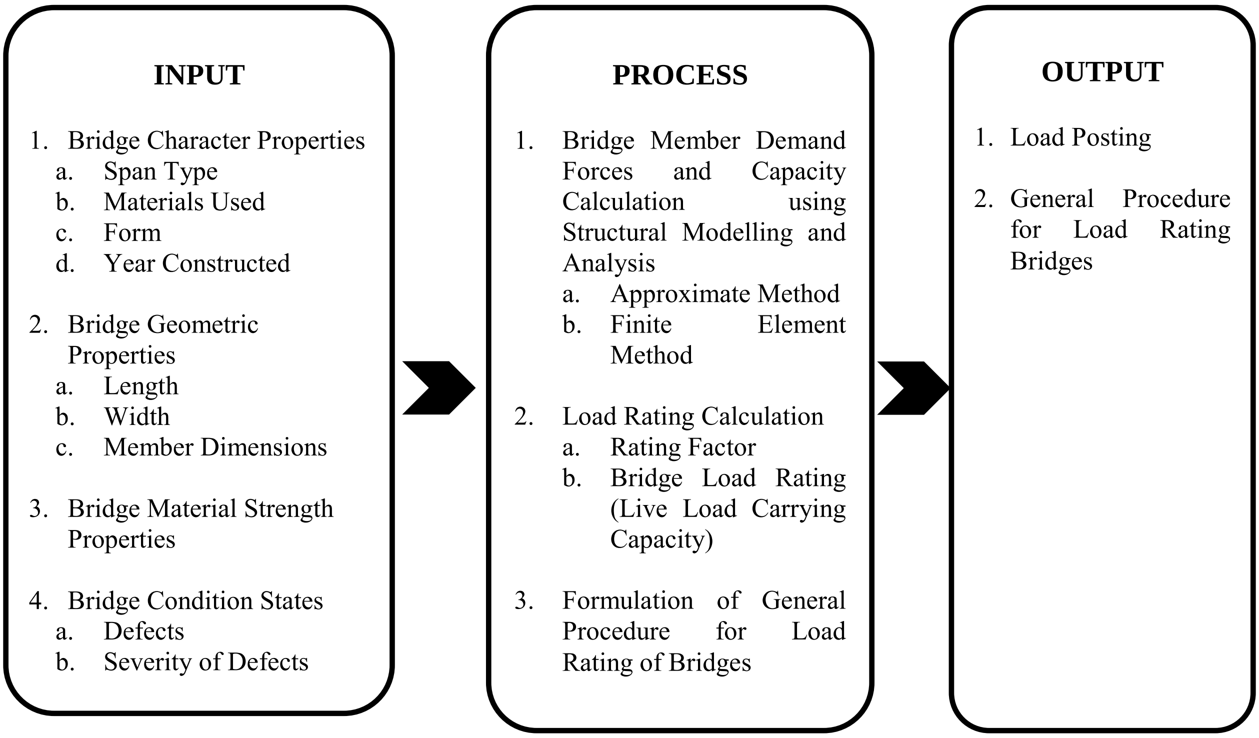

Fig. 9: Research Paradigm

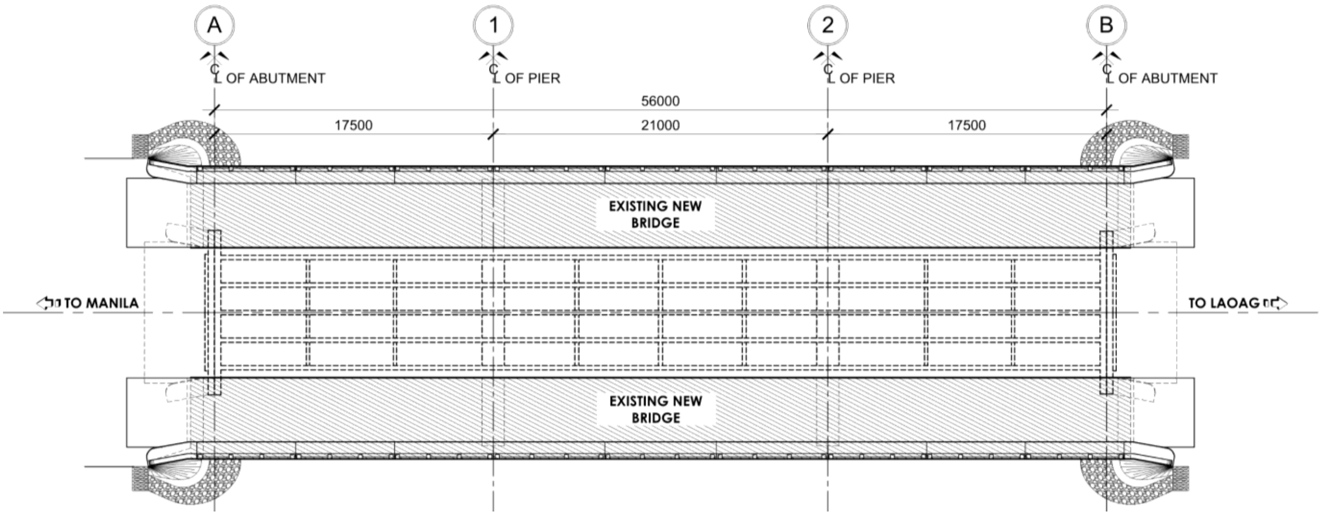

Fig. 10: Nilangoyan Bridge Plan

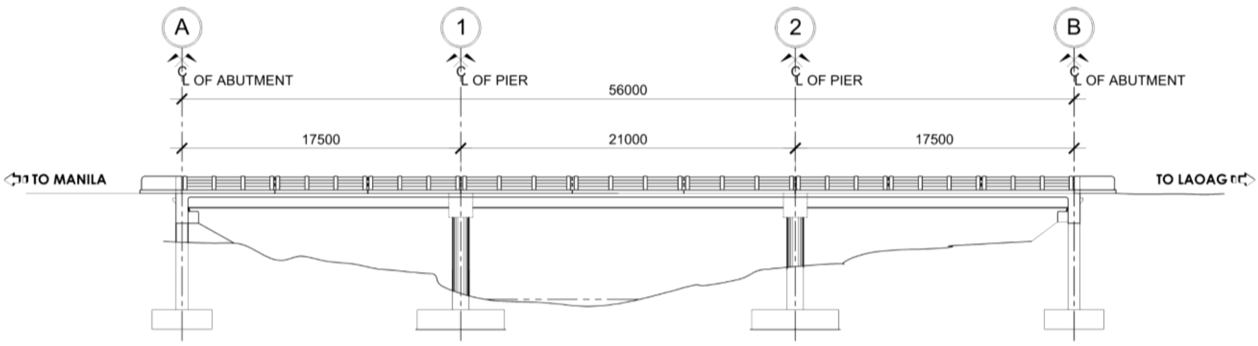

Fig. 11: Nilangoyan Bridge Profile

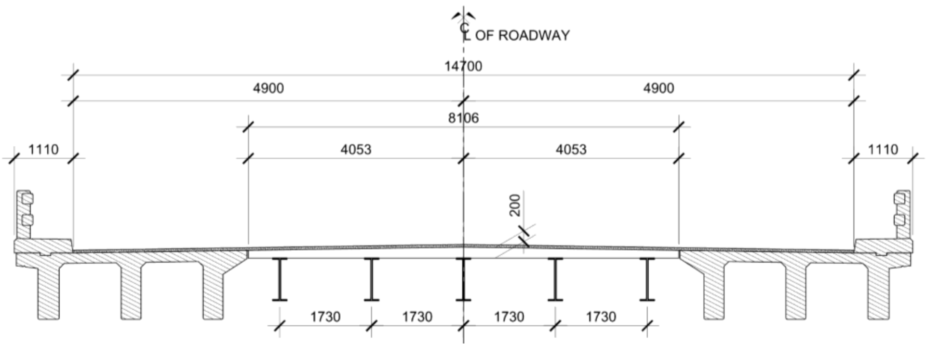

Fig. 12: Nilangoyan Bridge Typical Section

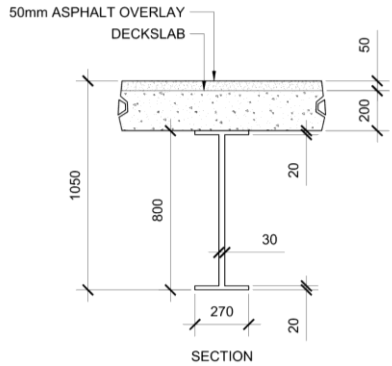

Fig. 13: Nilangoyan Bridge Typical Girder Section

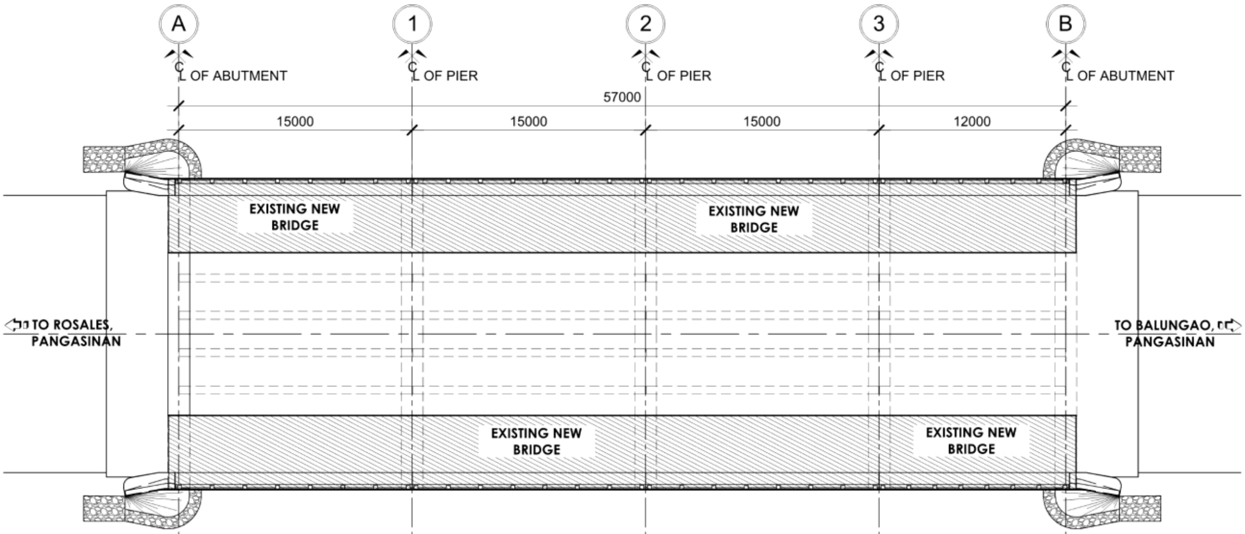

Fig. 14: Rodriguez Bridge Plan

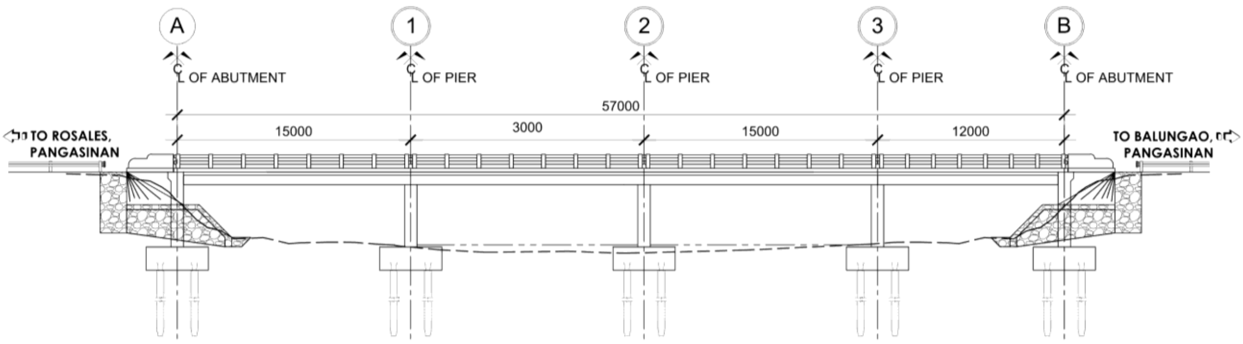

Fig. 15: Rodriguez Bridge Profile

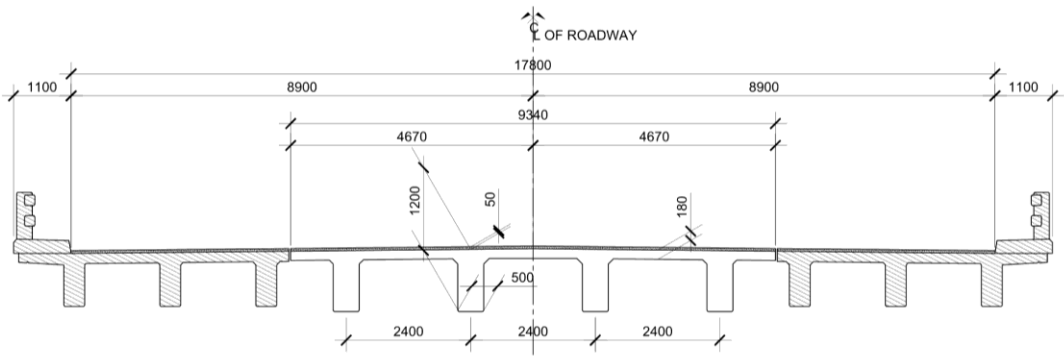

Fig. 16: Rodriguez Bridge Typical Section

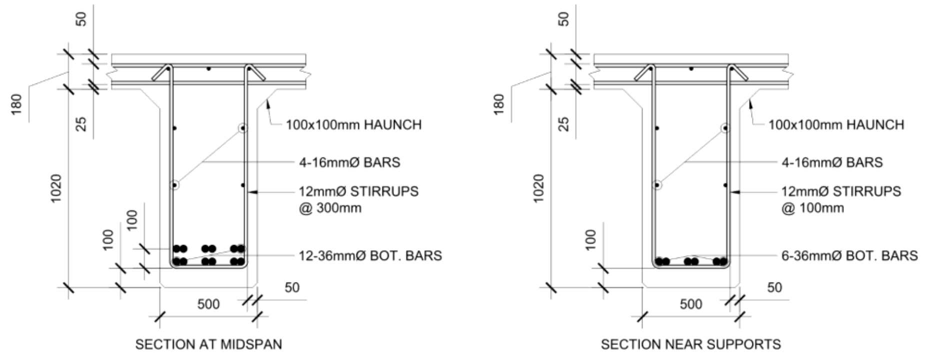

Fig. 17: Rodriguez Bridge Typical Girder Section

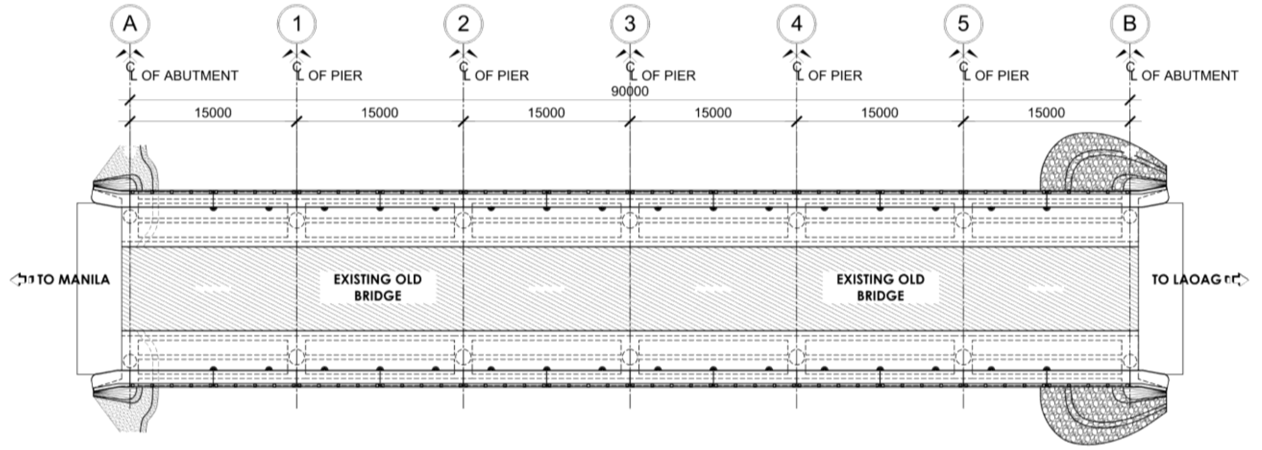

Fig. 18: Bayugao Bridge Plan

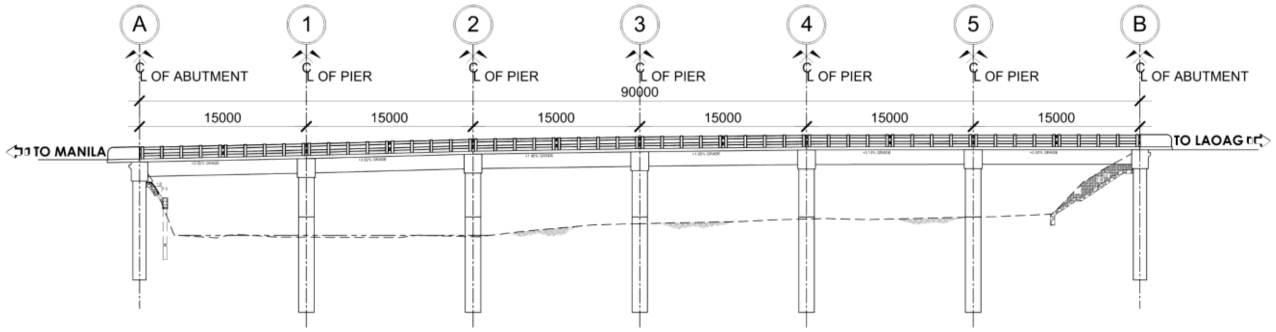

Fig. 19: Bayugao Bridge Profile

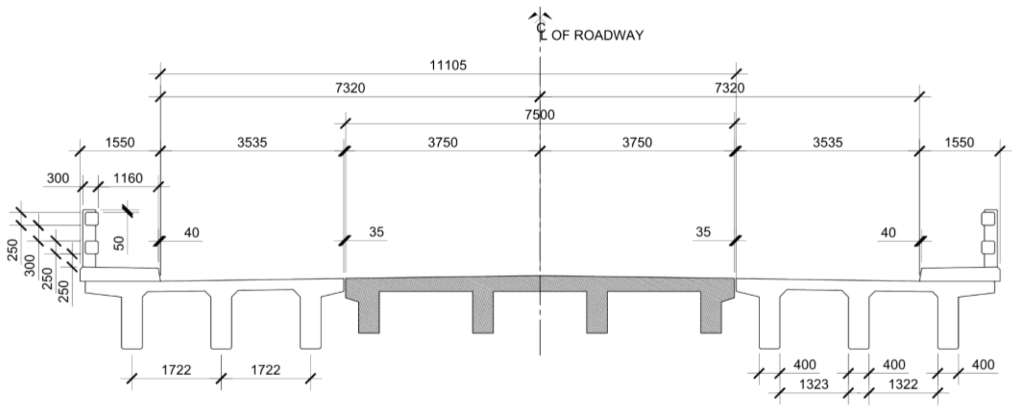

Fig. 20: Bayugao Bridge Typical Section

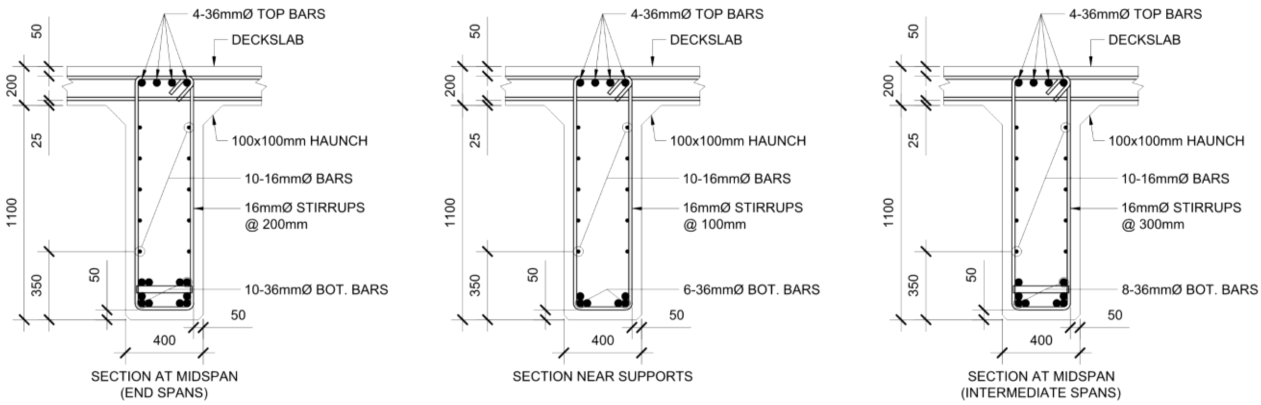

Fig. 21: Bayugao Bridge Typical Girder Section

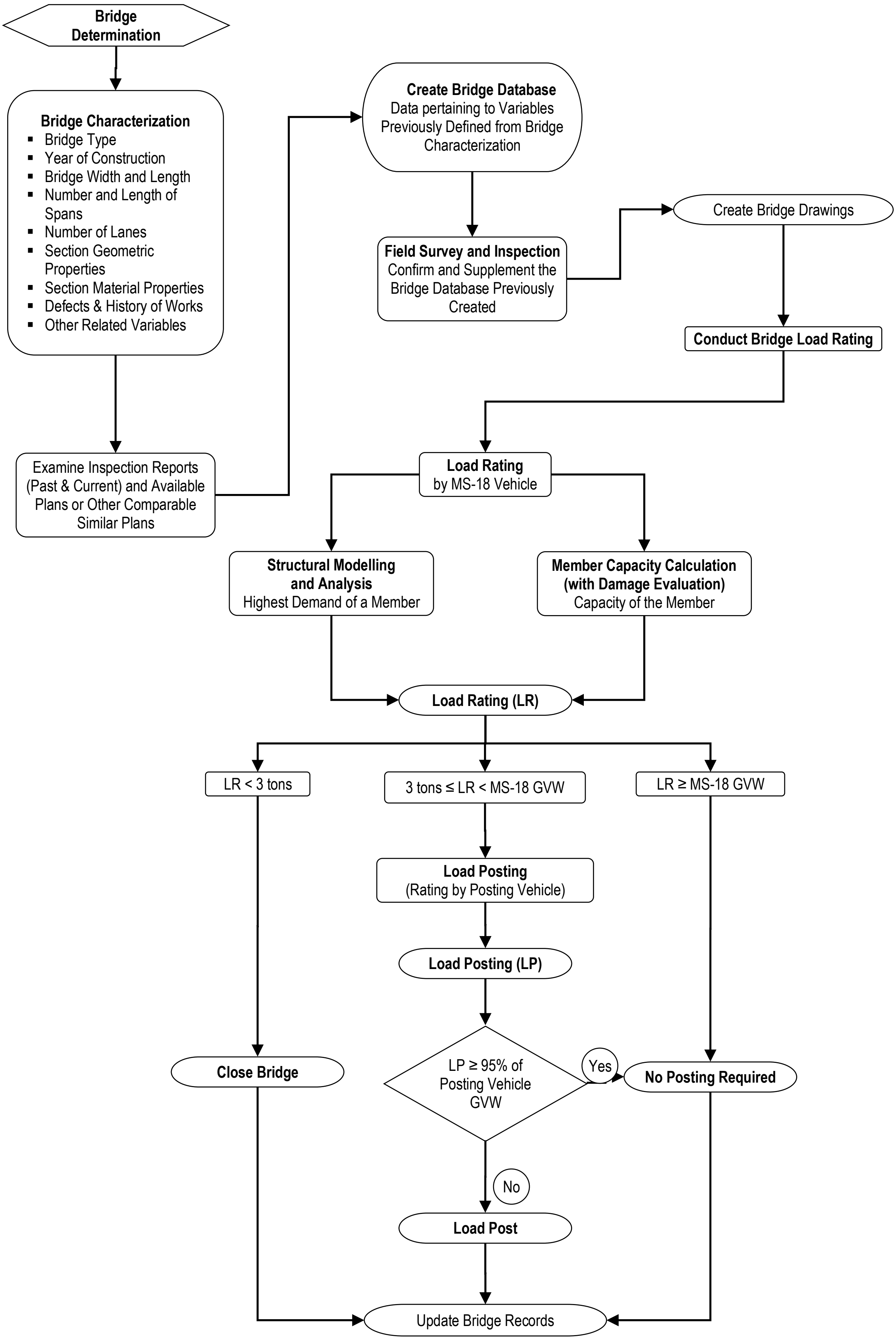

Fig. 22: General Load Rating Procedure

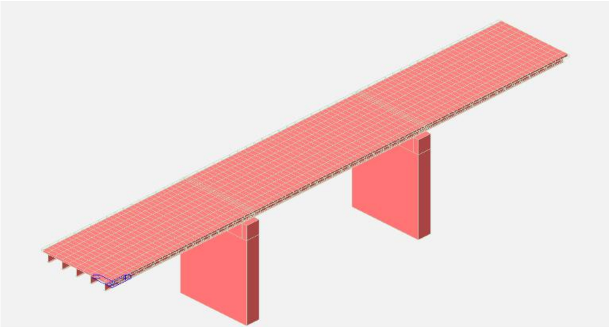
Fig. 23: Nilangoyan Br. MIDAS Civil Model

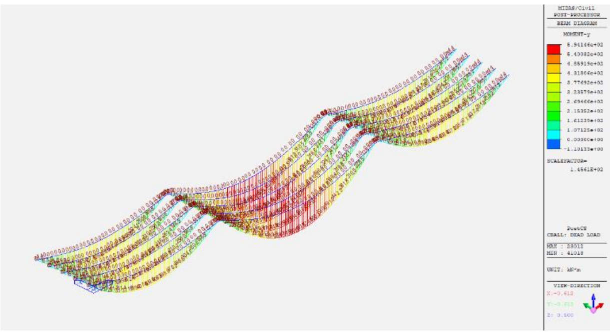
Fig. 24: Nilangoyan Br. DL-My Diagram

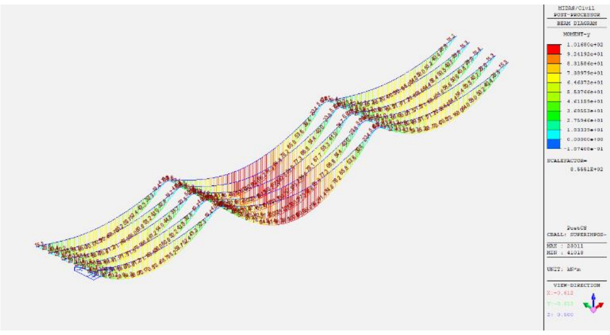
Fig. 25: Nilangoyan Br. SDL-My Diagram

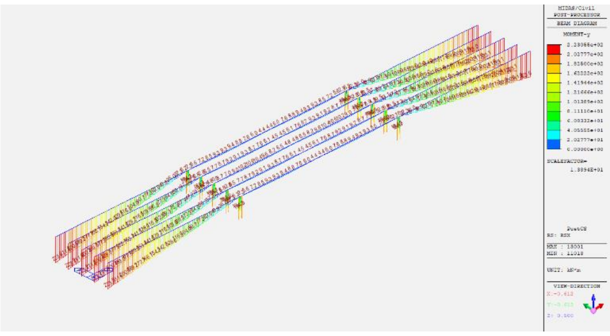
Fig. 26: Nilangoyan Br. EQ-My Diagram

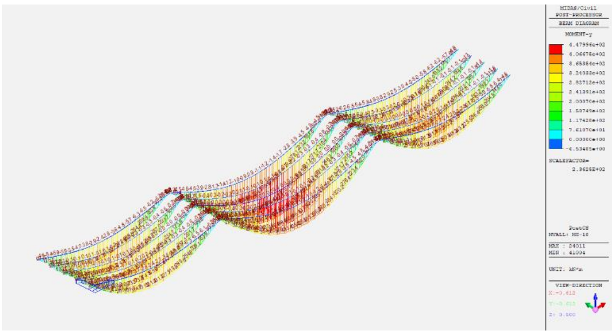
Fig. 27: Nilangoyan Br. MS-18-My Diagram

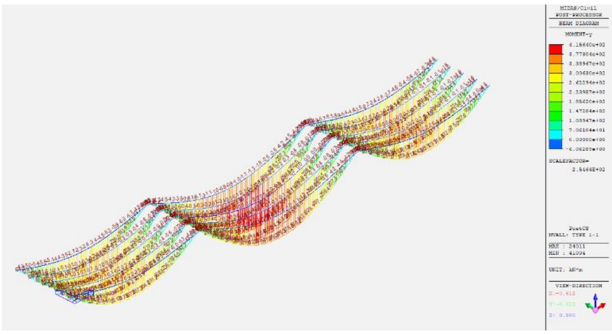
Fig. 28: Nilangoyan Br. Type1-1-My Diagram

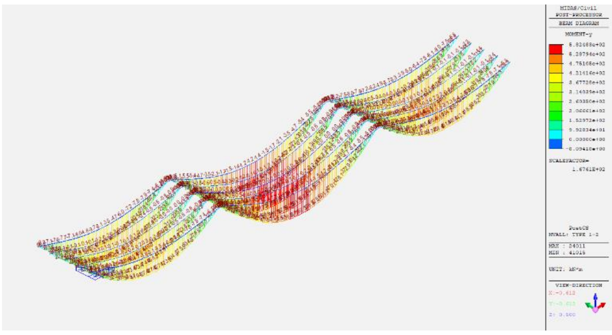
Fig. 29: Nilangoyan Br. Type1-2-My Diagram

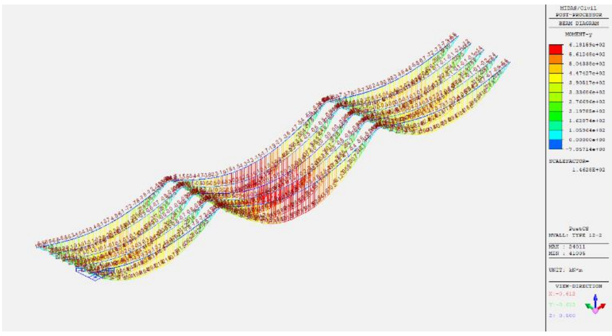
Fig. 30: Nilangoyan Br. Type12-2-My Diagram

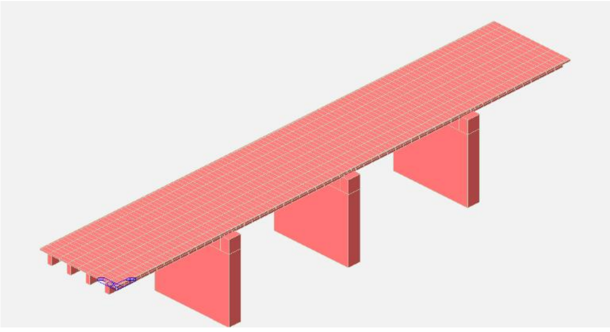

Fig. 31: Rodriguez Br. MIDAS Civil Model

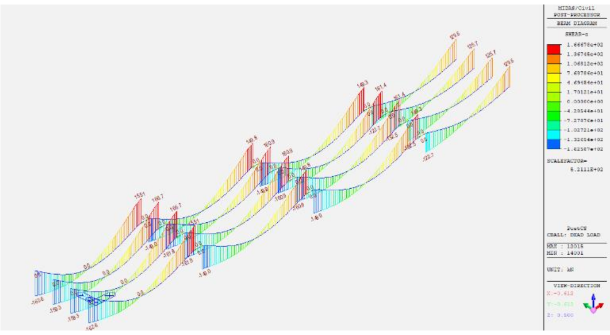

Fig. 32: Rodriguez Br. DL-Fz Diagram

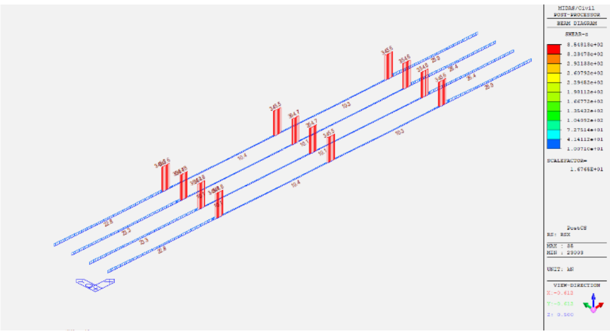

Fig. 33: Rodriguez Br. EQ- Fz Diagram

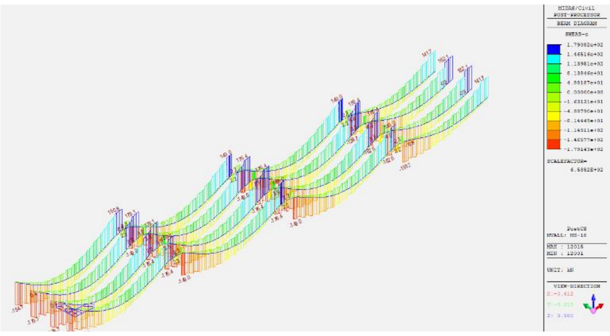

Fig. 34: Rodriguez Br. MS-18- Fz Diagram

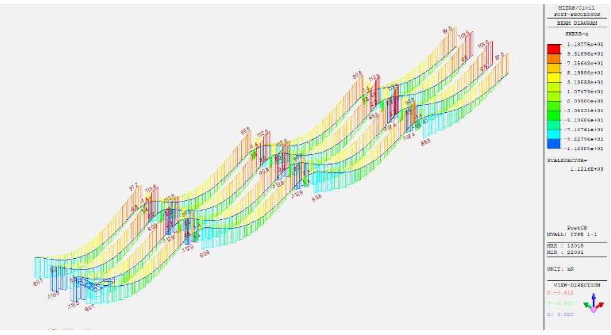

Fig. 35: Rodriguez Br. Type1-1- Fz Diagram

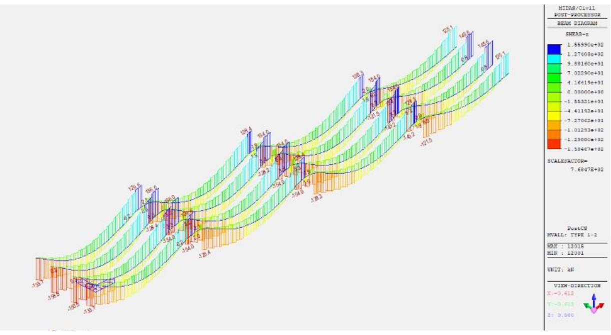

Fig. 36: Rodriguez Br. Type1-2- Fz Diagram

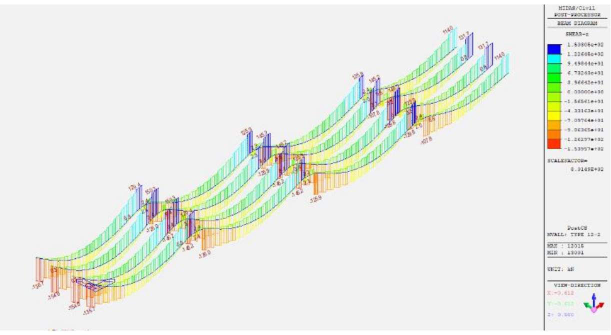

Fig. 37: Rodriguez Br. Type12-2- Fz Diagram

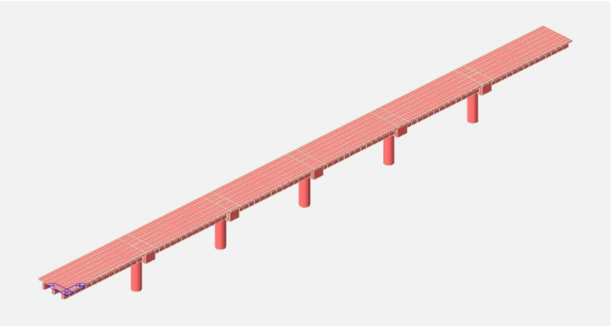

Fig. 38: Bayugao Br. MIDAS Civil Model

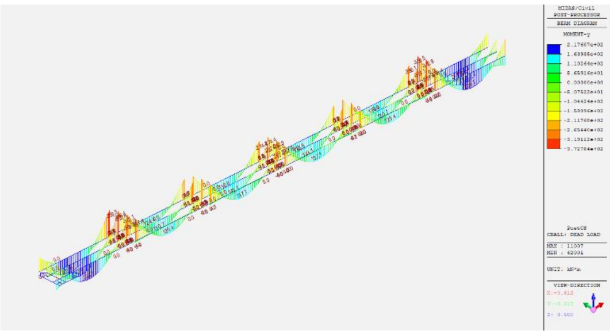

Fig. 39: Bayugao Br. DL-My Diagram

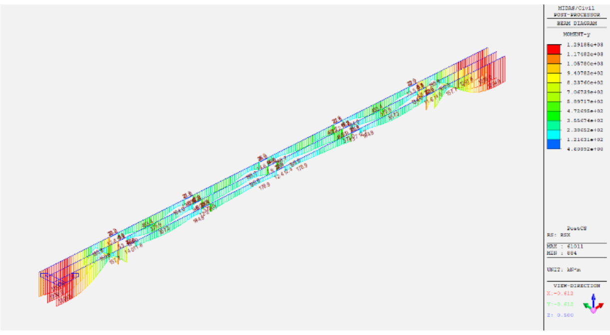

Fig. 40: Bayugao Br. EQ-My Diagram

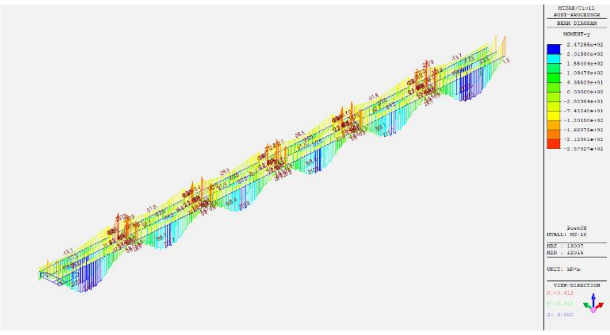

Fig. 41: Bayugao Br. MS-18-My Diagram

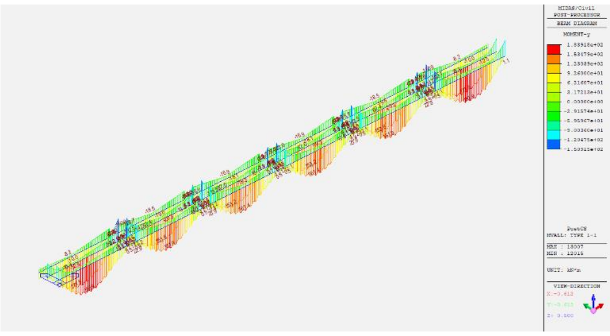

Fig. 42: Bayugao Br. Type1-1-My Diagram

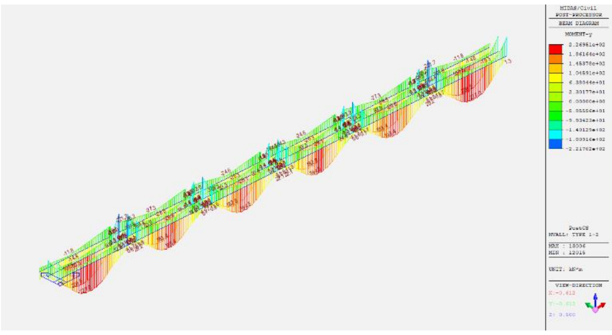

Fig. 43: Bayugao Br. Type1-2-My Diagram

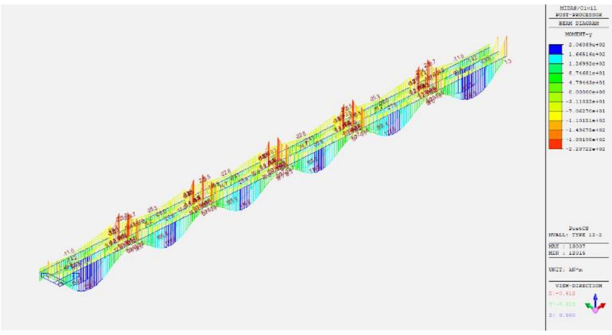

Fig. 44: Bayugao Br. Type12-2-My Diagram

Table 15. Nilangoyan Bridge (B02628LZ) Defects

Bridge Element	Bridge Attribute	Bridge Defect
Abutment	Main Structure	-Concrete Spalling/Scaling/Disinteg. -Reinforcing Bar Exposure/Corrosion
	Expansion Joint	-Water Leakage -Deteriorated Sealant
	Bearing	-Steel Bearing Corrosion
	Wingwall	-Concrete Cracks
Pier	Main Structure	-Concrete Spalling/Scaling/Disinteg. -Concrete Honeycomb -Reinforcing Bar Exposure/Corrosion
	Expansion Joint	-Deteriorated Sealant
Span	Deck	-Concrete Cracks -Concrete Spalling/Scaling/Disinteg. -Concrete Honeycomb -Water Leakage
	Main Member (Steel Girder)	-Steel Corrosion
	Railing	-Concrete Cracks -Concrete Delamination/Disinteg.

Table 16. Nilangoyan Br. Span Defects and Severity

Attribute	Severity	Defect
Span 1		
Deck	Poor	-Concrete Cracks
	Bad	-Concrete Spalling/Scaling/Disinteg.
	Bad	-Water Leakage
Railing	Fair	-Concrete Delamination/Disinteg.
Span 2		
Deck	Fair	-Concrete Cracks
	Fair	-Concrete Spalling/Scaling/Disinteg.
	Fair	-Concrete Honeycomb
	Bad	-Water Leakage
Main Member (Steel Girder)	Fair	-Steel Corrosion
Railing	Fair	-Concrete Cracks
Span 3		
Deck	Poor	-Concrete Cracks
	Poor	-Concrete Spalling/Scaling/Disinteg.
	Bad	-Water Leakage
Main Member (Steel Girder)	Bad	-Steel Corrosion
Railing	Fair	-Concrete Cracks

Table 17. Rodriguez Bridge (B00749LZ) Defects

Bridge Element	Bridge Attribute	Bridge Defect
Abutment	Slope/Bank Protection	-Concrete Cracks -Slope Erosion
	Expansion Joint	-Water Leakage -Abnormal Space/Noise
	Bearing	-Steel Bearing Corrosion
Pier	Expansion Joint	-Water Leakage -Abnormal Space/Noise
	Bearing	-Steel Bearing Corrosion -Paint Deterioration
	Foundation	-Scouring
Span	Deck	-Concrete Cracks -Concrete Spalling/Scaling/Disinteg. -Concrete Delamination -Concrete Honeycomb -Water Leakage
	Main Member (RC Girder)	-Concrete Cracks

Table 18. Rodriguez Br. Span Defects and Severity

Attribute	Severity	Defect
	Span 1	
Deck	Bad	-Concrete Spalling/Scaling/Disinteg.
Main Member (RC Girder)	Bad	-Concrete Cracks
	Span 2	
Deck	Bad Bad Bad	-Concrete Cracks -Concrete Spalling/Scaling/Disinteg. -Concrete Delamination
Main Member (RC Girder)	Bad	-Concrete Cracks
	Span 3	
Deck	Bad	-Concrete Spalling/Scaling/Disinteg.
Main Member (RC Girder)	Bad	-Concrete Cracks
	Span 4	
Deck	Bad	-Concrete Spalling/Scaling/Disinteg.
Main Member (RC Girder)	Bad	-Concrete Cracks