Structural Load Rating and Long-Term Rehabilitation Cost Estimate for the El Prieto Bridge

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Outline

- Introduction
- Experimental Evaluation
- Structural Analysis
- State Limits Analysis
- Results
- Conclusions

Introduction

“El Prieto” Bridge location next to the Port of Tampico

Introduction

Satellite view of the bridge

Introduction

Bridge's General Data

Age: 26 years

Owned by: State of Veracruz (toll bridge)

Superstructure: 23 simple spans with lengths from 8.15 m to 25 m. Spans are reinforced concrete slabs with 4 I beams and steel frames.

Total length: 526.85 m

Wide: 11 m

Substructure: Steel frame piles made up from discharged oil pipe.

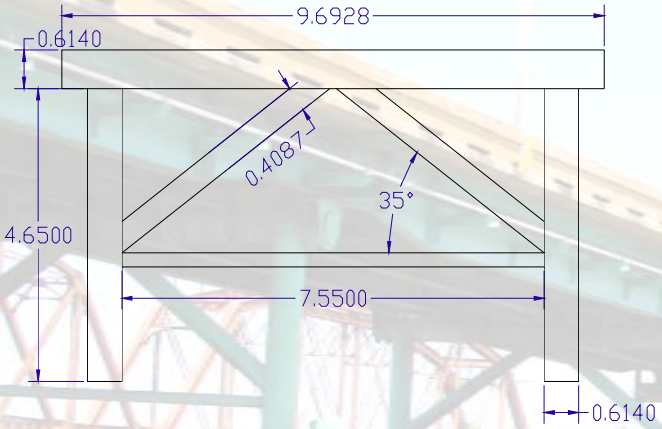
Traffic: 3093 vehicles per day (14% trucks, 2% bus and 84% light vehicles)

Introduction

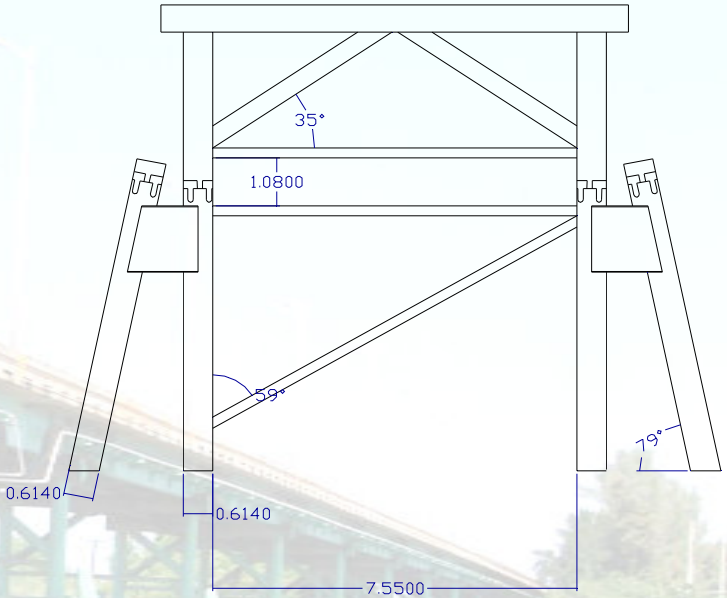
Span No.	Span Length (m)
1	8.15
2	24.5
3	25
4	25
5	25
6	25
7	25
8	25
9	25
10	25
11	25
12	25

Span No.	Span Length (m)
13	25
14	25
15	25
16	25
17	12.5
18	38.2
19	14
20	38.2
21	8.15
22	25
23	8.15

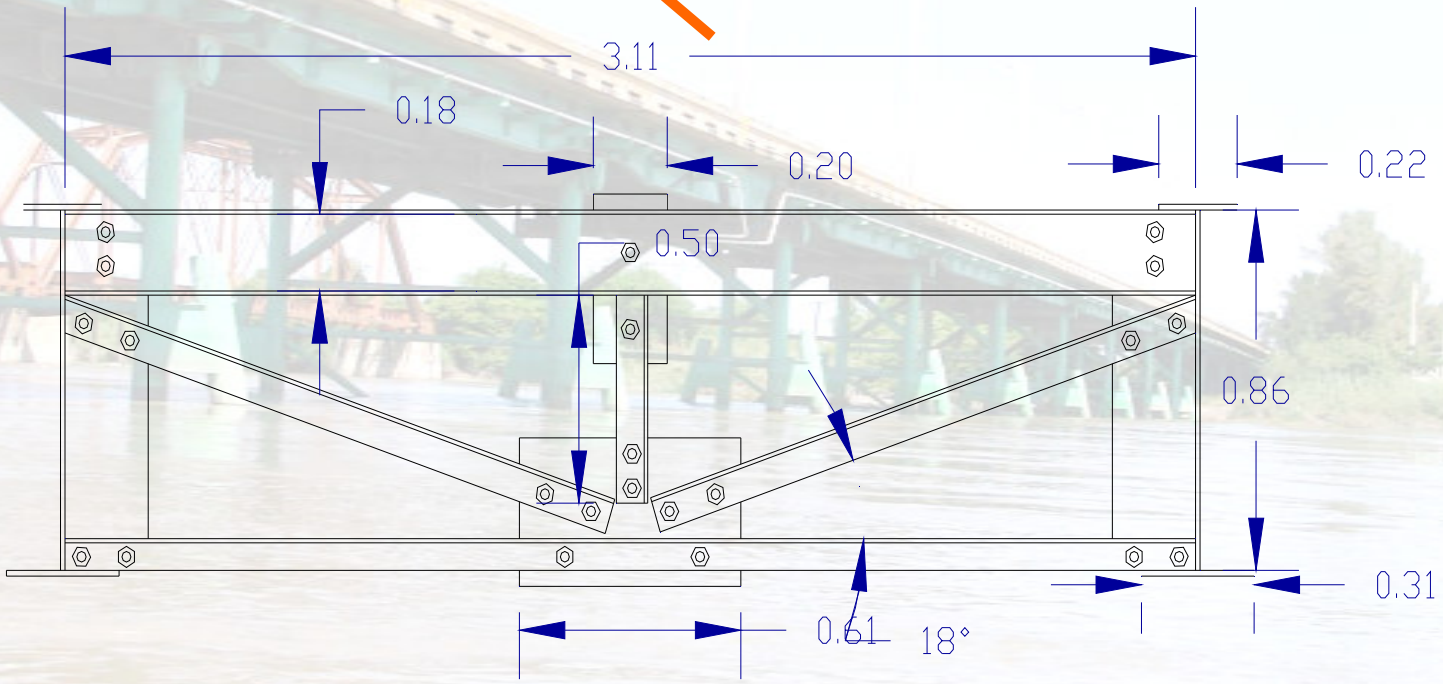
There are two types of frame piles. Type A, used for ground piles; and type B for water piles.



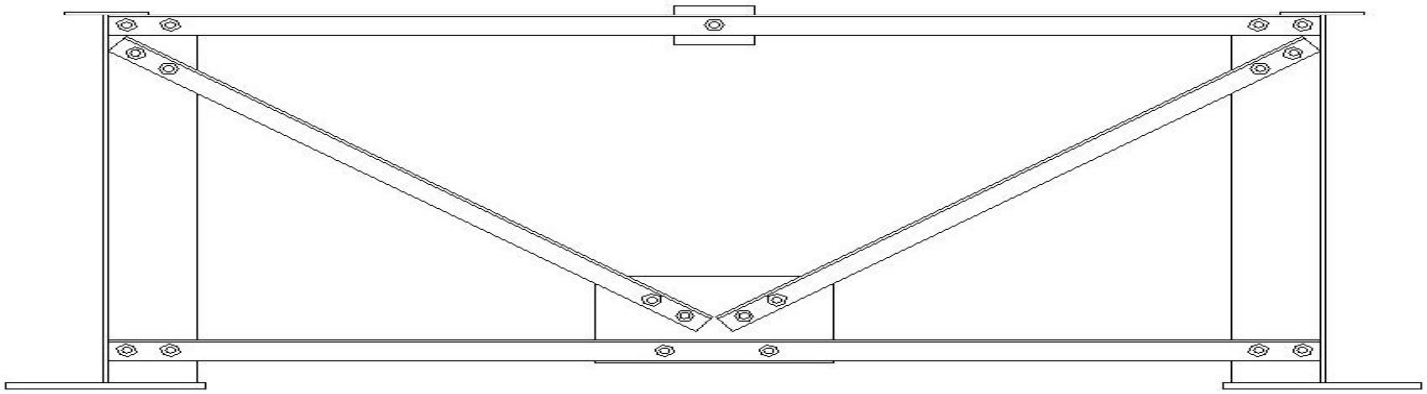
Type A



Type B



Frame for lateral stiffness of the superstructure and supporting to the frame piles



Frame for lateral stiffness of the superstructure

Experimental Evaluation

Field Studies

- Geometrical and damage inventory
- Bridge dynamic testing
- Corrosion evaluation

Geometric and damage inventory

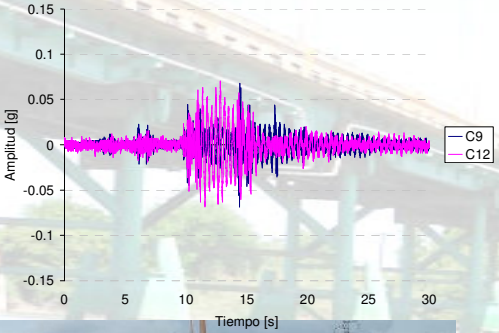
- Visual inspection for damage identification.
- Direct measurement for geometrical parameters.
- Pipe thickness measured using an ultrasonic technique.

Bridge dynamic testing

Dynamic tests on controlled conditions for modal analysis.

20 uniaxial accelerometers

4 triaxial accelerometers



Corrosion evaluation

- Chemical analysis to evaluate carbonation and chloride ion in concrete cores from the bridge deck.
- Potential or voltage measurements to evaluate electrochemical corrosion activity.
- Evaluation of cathodic protection system in steel piles.

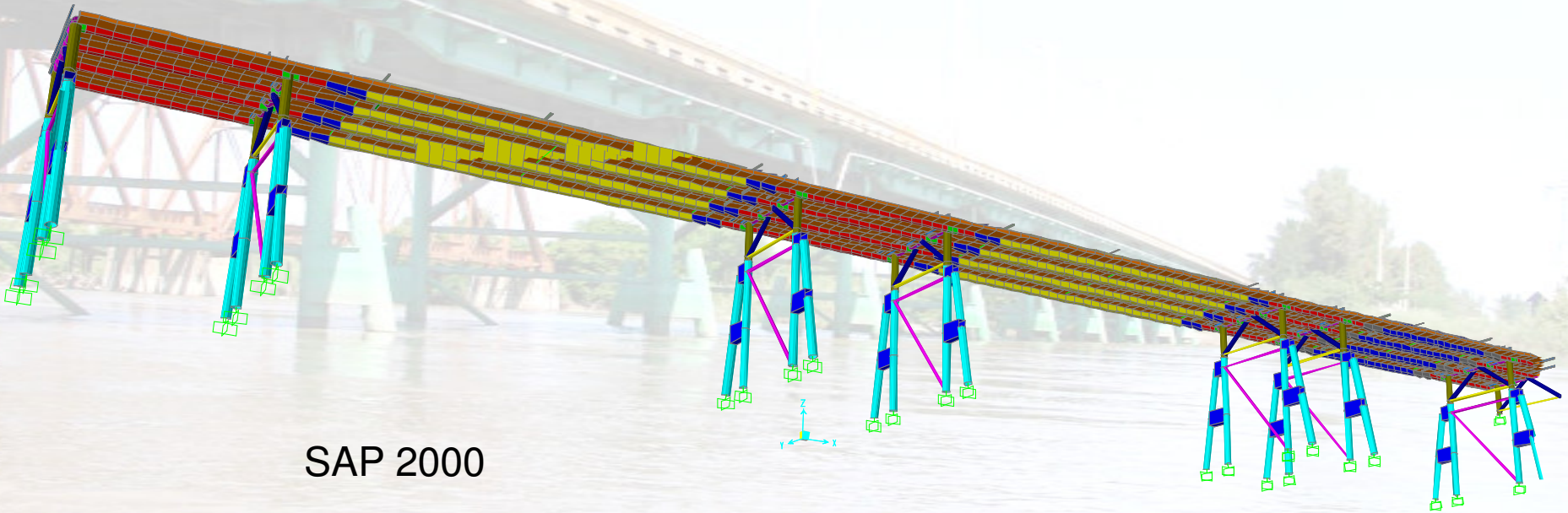
Structural Analysis

Objective

- Evaluate structural condition of the bridge.
- Calculate the total rehabilitation cost to reach an optimal condition (zero condition).
- Calculate the maintenance and operational costs of the bridge to keep optimal condition.
- Estimate the toll fee according to the present traffic condition.
- Evaluate the possibility to lease the operation and maintenance of the bridge to a private company.

Structural Analysis

Calibrated finite element model



SAP 2000

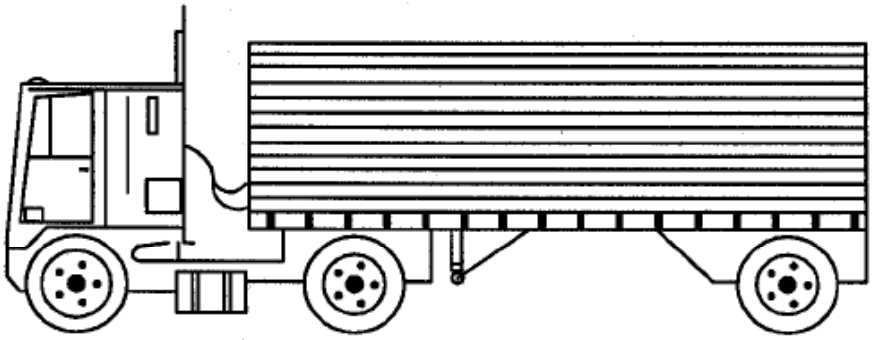
State Limit Analysis

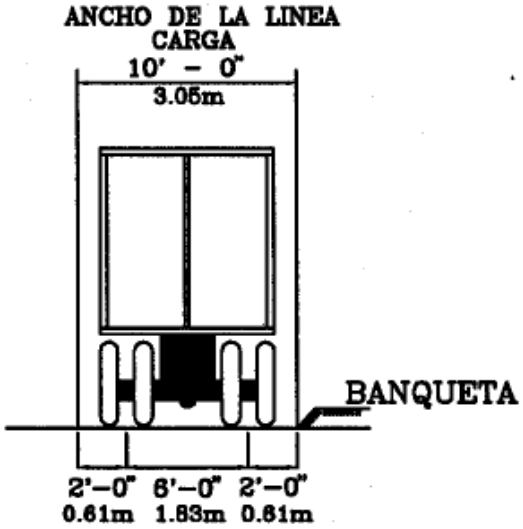
Loads

- Dead loads
- Live loads based on:
  - AASHTO code criteria when the bridge was designed
  - AASHTO present code criteria
  - Instituto Mexicano del Transorte's (IMT's) code criteria
- Wind loads
- Seismic loads

State Limit Analysis

AASHTO model when bridge was built





HS20–44	8,000 Lbs 3,632 Kgs	32,000 Lbs 14,528 Kgs	32,000 Lbs 14,528 Kgs
HS15–44	6,000 Lbs 2,724 Kgs	24,000 Lbs 10,896 Kgs	24,000 Lbs 10,896 Kgs

Truck type HS15-44 y HS20-44

State Limit Analysis

AASHTO model when bridge was built

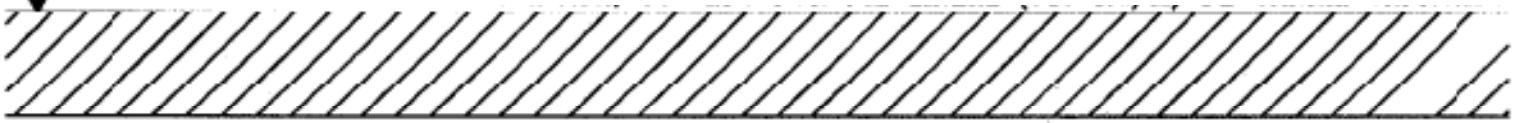
Concentrated Load: 16000 lbs (8172 kg) for moment
26000 lbs (11804 kg) for shear

Uniform load, 640 lbs per ft (953.3 kg/m) on loaded lane

H20-44 and HS20-44 Loads

Concentrated Load: 13500 lbs (6129 kg) for moment
19500 lbs (8853 kg) for shear

Uniform load, 480 lbs per ft (715 kg/m) on loaded lane

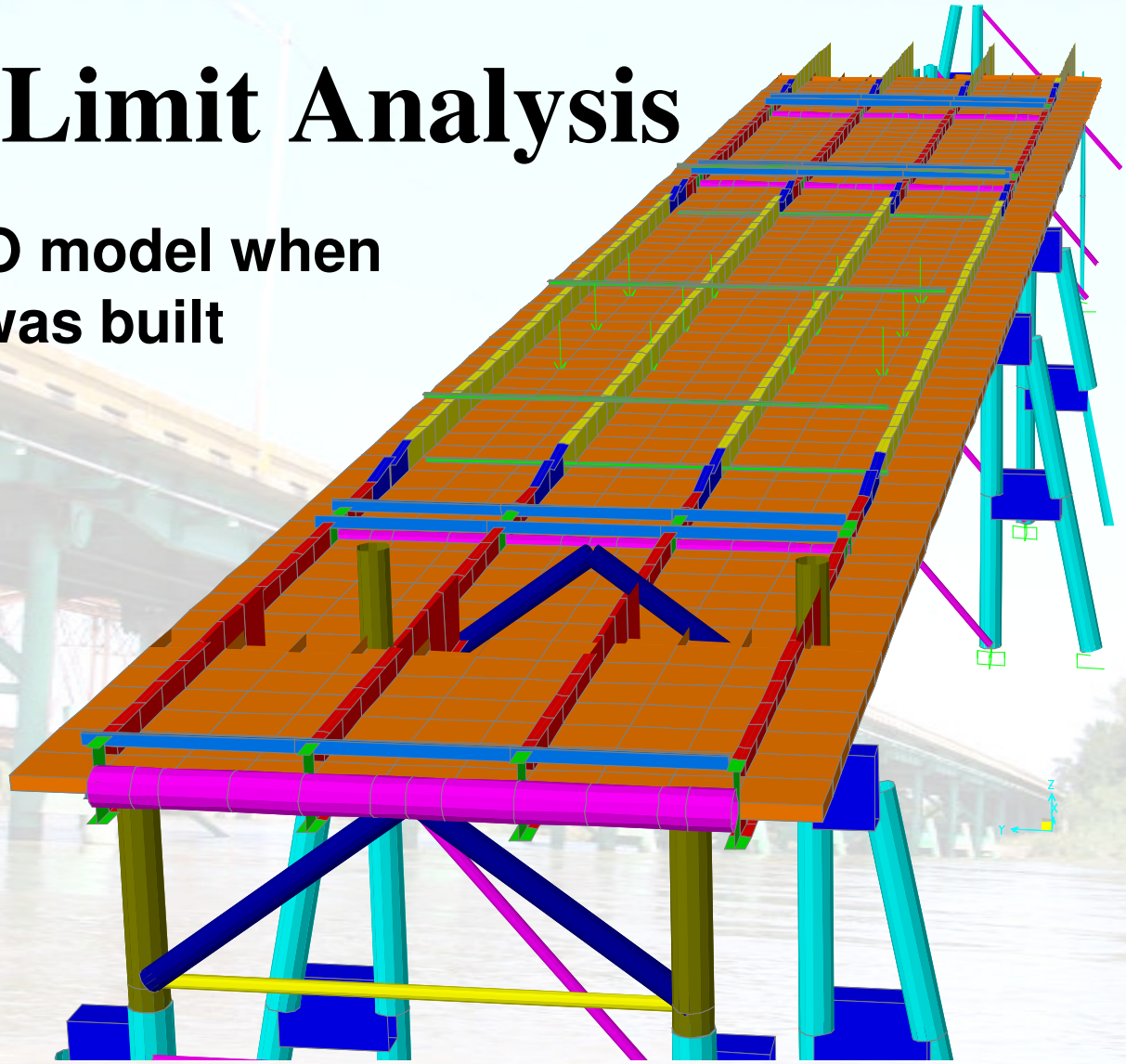


H15-44 and HS15-44 Loads

Uniform and concentrated loads

State Limit Analysis

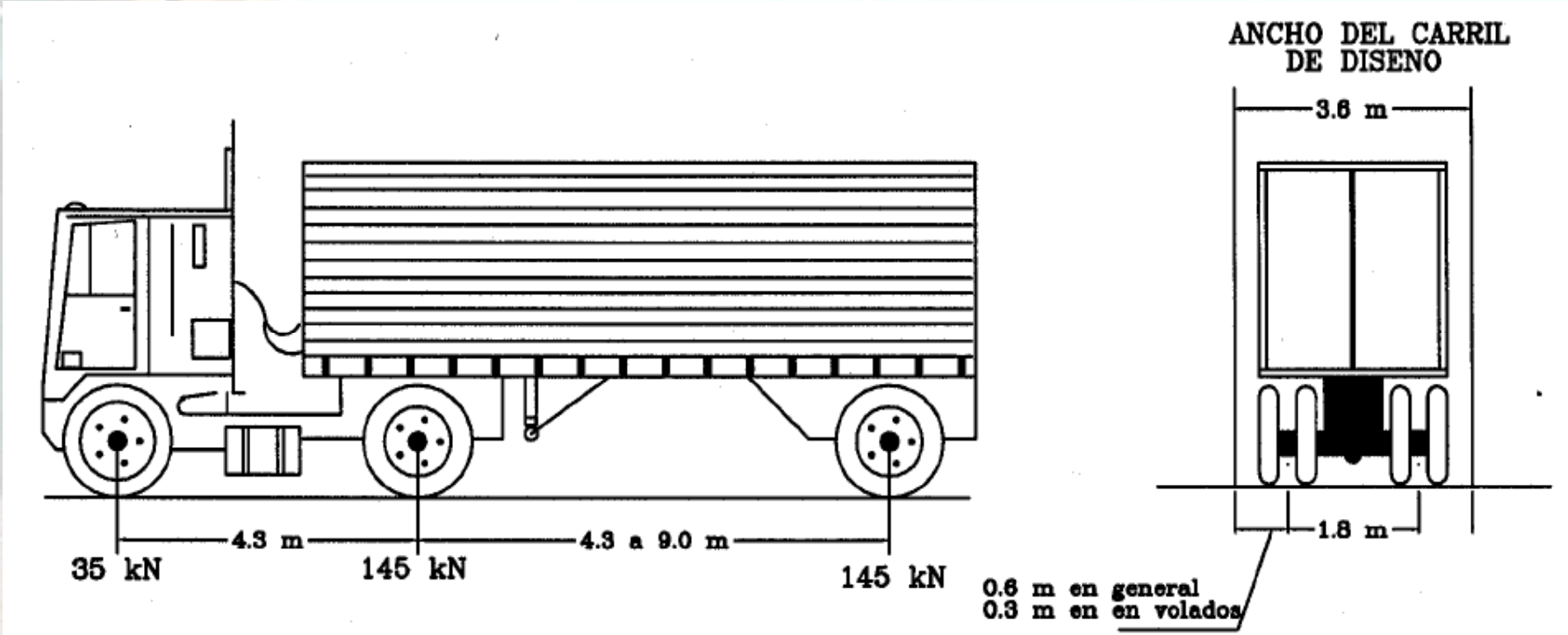
AASHTO model when bridge was built



Load hypothesis 2 with 2 HS20 truck at the center of 38m span

State Limit Analysis

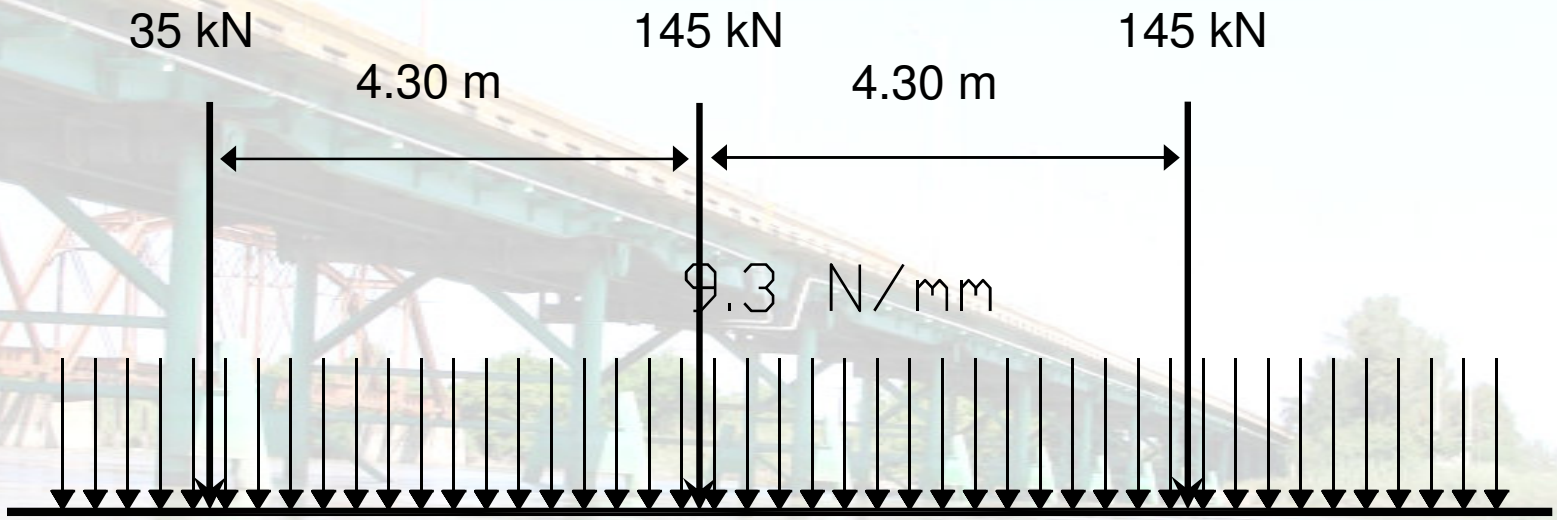
Actual AASHTO Model



Load truck model HL-93

State Limit Analysis

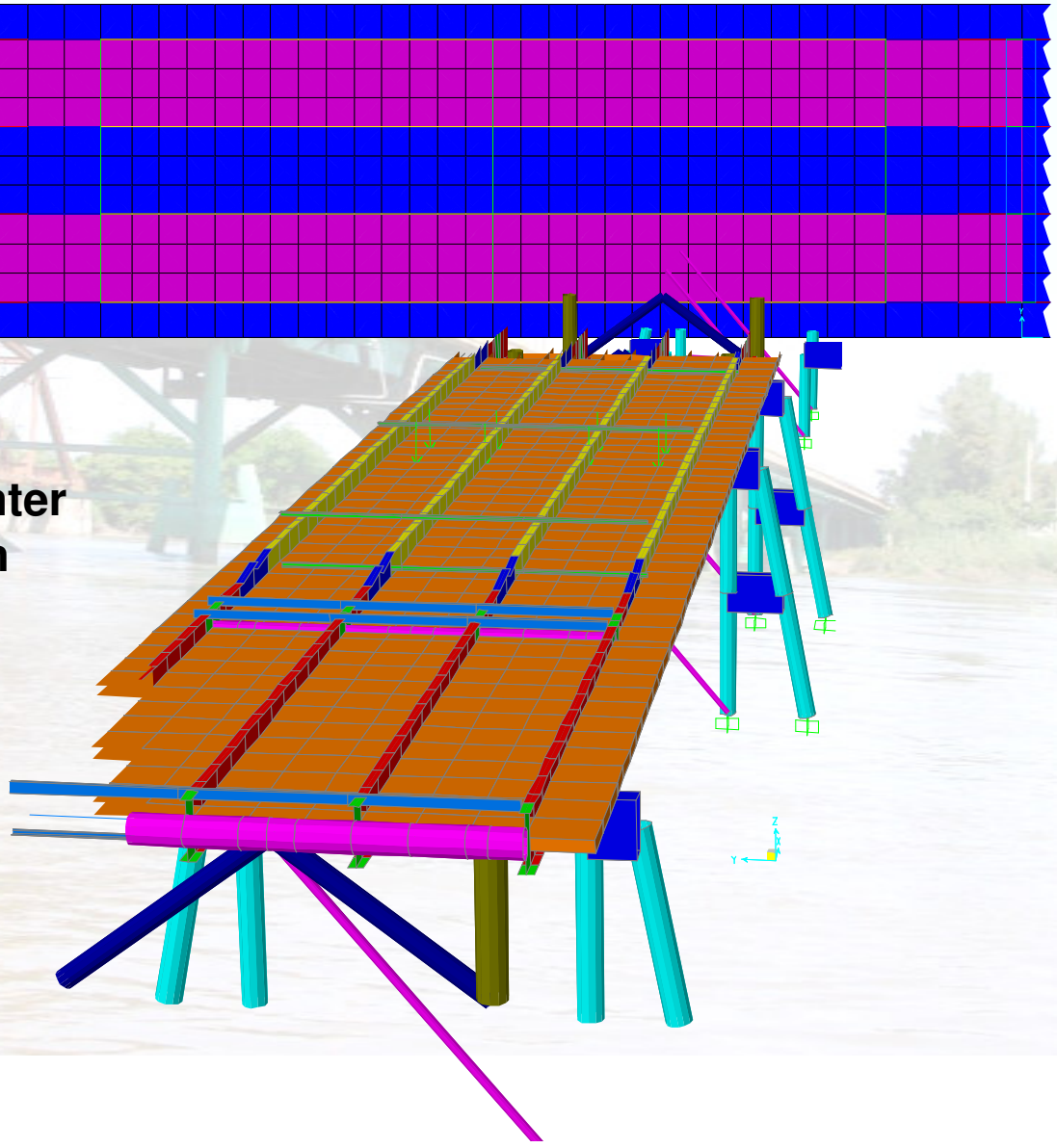
Actual AASHTO Model



Uniform load and concentrated loads for HL-93 model

State Limit Analysis

Actual AASHTO model

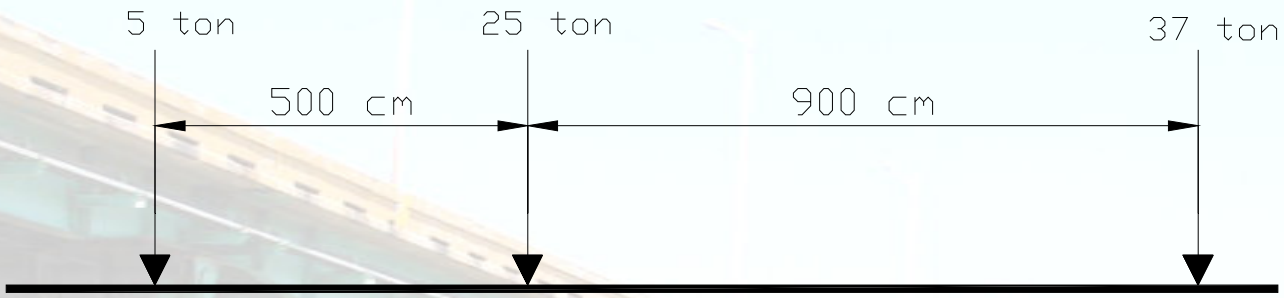


Load hypothesis 13. Two trucks at the center of the 38 m span with uniform distributed load.

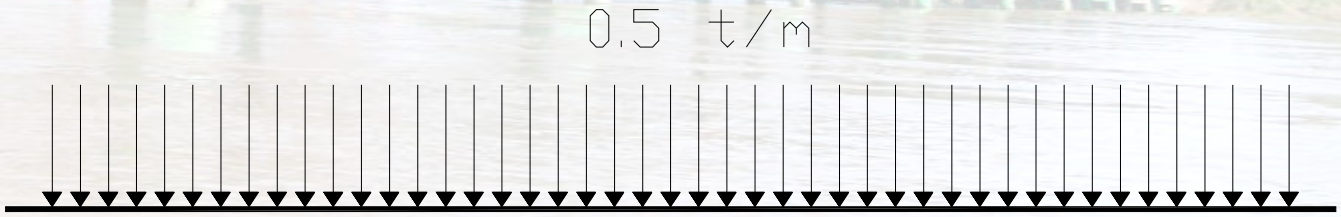
Dynamic load is also considered.

State Limit Analysis

IMT's model



Truck loads in the IMT model



Uniform load in the IMT model

State Limit Analysis

- **Service State Limit (SSL)**

Load Type	Maximum deflection
Steel, aluminum and concrete bridges	
General truck loads	Span/800
Truck loads and/or pedestrians	Span/1000
Truck loads in cantilever	Span/300
Truck loads and/or pedestrians in cantilever	Span/375

For the 38 m span, maximum deflection is 0.04750 m
For the 25 m span, maximum deflection is 0.03125 m.

State Limit Analysis

- **Resistance State Limit (RSL)**

Load Conditions

1.50 DL	**(Strenght-IV)**
1.25 DL +1.75 LL	**(Strenght-I)**
1.25 DL + 1.4 WL	**(Strenght-III)**
1.25 DL + 1.35 LL + 0.4 WL	**(Strenght-V)**
0.90 DL + 1.0 EL	**(Extreme-I)**
1.25 DL + 0.5 LL +1.0 EL	**(Extreme-I)**

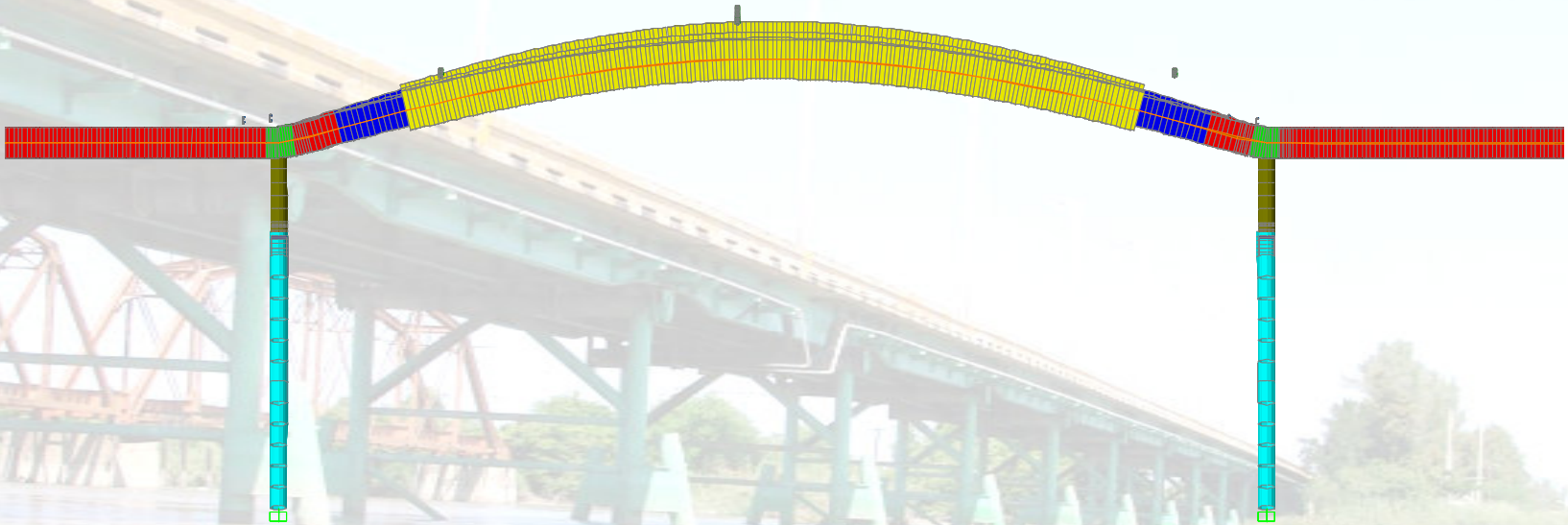
DL - Dead Load
LL - Live Load
WL - Wind Load
EL - Seismic Load

Results

TABLE: Modal Periods And Frequencies

OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	0.448355	2.2304	14.014	196.39
MODAL	Mode	2	0.446498	2.2397	14.072	198.03
MODAL	Mode	3	0.443346	2.2556	14.172	200.85
MODAL	Mode	4	0.442482	2.26	14.2	201.64
MODAL	Mode	5	0.291683	3.4284	21.541	464.02
MODAL	Mode	6	0.265356	3.7685	23.678	560.66
MODAL	Mode	7	0.230956	4.3298	27.205	740.12
MODAL	Mode	8	0.22785	4.3889	27.576	760.43
MODAL	Mode	9	0.218766	4.5711	28.721	824.9
MODAL	Mode	10	0.218749	4.5714	28.723	825.02
MODAL	Mode	11	0.158441	6.3115	39.656	1572.6
MODAL	Mode	12	0.138435	7.2236	45.387	2060
MODAL	Mode	13	0.138372	7.2269	45.408	2061.9
MODAL	Mode	14	0.13582	7.3627	46.261	2140.1
MODAL	Mode	15	0.135307	7.3906	46.437	2156.4

Results



First vibration mode for the 38 m span (0,448 sec period)

Results

Service State Limite (SSL)

Load hypothesis	Model	Displacement at the center of the 38 m span (m)	Service State Limit SSL (m)	Disp/SSL
Hip. 1 Dead load		0.0337	0.0475	0.71
CombELS 2	AASHTO old	0.0637	0.0475	1.34
CombELS 8	AASHTO new	0.078	0.0475	1.64
CombELS 11	IMT	0.0758	0.0475	1.60

Results

Resistance State Limit (RSL)

The worst case scenario was given by:

CombELR 6 = 1.25 Dead Load + 1.75 Live Load (Uniform + Truck)

Results

Flelxural stress at the center of the 38 m span

$$\sigma = n \frac{M}{I} y$$

M =	1,550.20	ton-m
I =	0.15	m^4
y =	1.40	m
n =	4	
σ =	58,488.64	ton/m^2
σ =	5,848.86	kg/cm^2

Greater than the σ_y for steel.

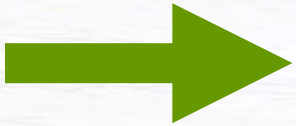
NOT ACCEPTED

Results

Flexural stress at the center of the 25 m span

$$\sigma = n \frac{M}{I} y$$

M =	627.30	ton-m
I =	0.15	m^4
y =	1.40	m
n =	4	
σ =	23,667.86	ton/m^2
σ =	2,366.79	kg/cm^2



To the limit

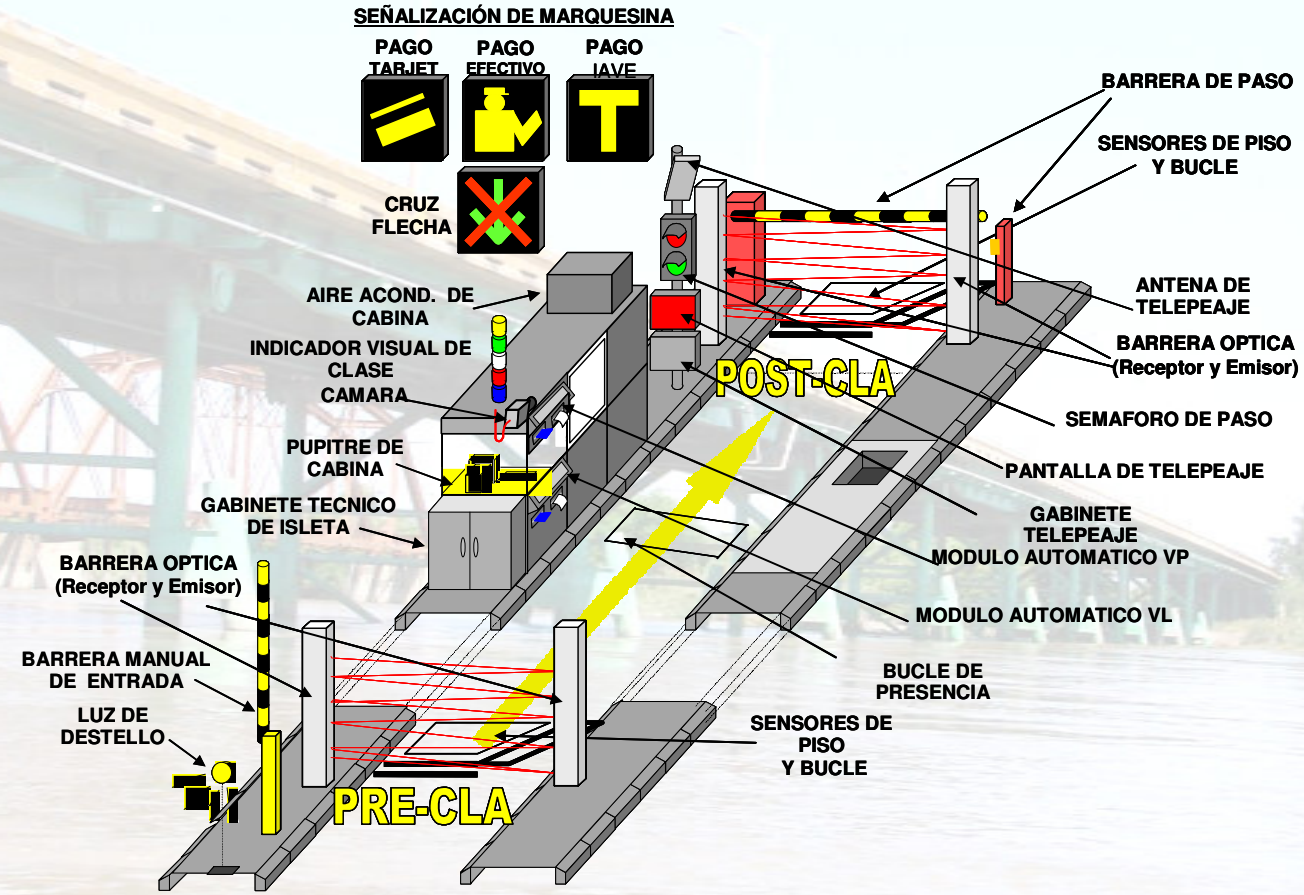
Results

Bridge rating according to the SCT criteria

0	New bridge or recently repaired, with no problems
1	Bridge in good condition. No special attention required
2	Bridge with minor problems, long term monitoring
3	Bridge with significant damage, repair required within 3 to 5 years
4	Severe damage, repair within 1 to 2 years
5	Extreme damage or total failure risk, inmediate repair required

Bridge qualification is **3**

Results


SEÑALIZACIÓN DE MARQUESINA
PAGO TARJET
PAGO EFECTIVO
PAGO AVE
CRUZ FLECHA
BARRERA DE PASO
SENSORES DE PISO Y BUCLE
ANTENA DE TELEPEAJE
BARRERA OPTICA (Receptor y Emisor)
SEMAFORO DE PASO
PANTALLA DE TELEPEAJE
GABINETE TELEPEAJE
MODULO AUTOMATICO VP
MODULO AUTOMATICO VL
BUCLE DE PRESENCIA
SENSORES DE PISO Y BUCLE
AIRE ACOND. DE CABINA
INDICADOR VISUAL DE CLASE
CAMARA
PUPITRE DE CABINA
GABINETE TECNICO DE ISLETA
BARRERA OPTICA (Receptor y Emisor)
BARRERA MANUAL DE ENTRADA
LUZ DE DESTELLO
POST-CLA
PRE-CLA

Results

Rehabilitation costs to get optimal condition

	Conceptos	Costo
1	Reforzamiento de los claros de 38 m y 25 m (451 ml de puente)	17,138,000
2	Sustitución del parapeto de concreto por uno más ligero y moderno	1,009,920
3	Reparación de juntas de dilatación	1,009,800
4	Reposición y arreglo de los ánodos de sacrificio para la protección catódica	368,000
5	Aplicar pintura anticorrosiva a la estructura metálica	575,260
6	Limpieza de apoyos de neopreno y calefateo de grietas en la losa	173,500
7	Poner en funcionamiento el alumbrado del puente	75,000
	TOTAL	**20,349,480**

	Conceptos	Costo
1	Arreglar los tramos de camino que dan acceso al puente	1,371,000
2	Modernizar el sistema de peaje y carriles	732,000
	TOTAL	**2,103,000**

TOTAL : $ **22,452,480 MP = $ 2,041,134 USD**

Results

Regular maintenance cost

Actividades de mantenimiento menor
LIMPIEZA DE LA SUPERFICIE DE RODAMIENTO PAPELEO A MANO
LIMPIEZA DE SEÑALAMIENTO VERTICAL BAJO
LIMPIEZA DE SEÑALAMIENTO VERTICAL ALTO
PINTURA DE DE SEÑALAMIENTO VERTICAL BAJO
PINTURA DE DE SEÑALAMIENTO VERTICAL ALTO
REPOSICION DE VIELETAS
LIMPIEZA DE JUNTAS DE DILATACION DE ESTRUCTURAS
PINTURA DE POSTES DE ALUMBRADO PUBLICO
REPOSICION DE LAMPARAS
DESPINTADO DE PROPAGANDA COLOCADA EN MUROS
LIMPIEZA Y PINTURA DE PARAPETO
LIMPIEZA PROFUNDA EN BARRERA LATERAL
PINTURA, REFLEJANTE EN RAYA DISCONTINUA (BLANCA O AMARILLA) DE 15 CM DE ANCHO
PINTURA, REFLEJANTE EN RAYA CONTINUA (BLANCA O AMARILLA) DE 15 CM DE ANCHO

+

Actividades de mantenimiento menor	P.U.	Unidad	Cantidad	Importe
BACHEO CON MEZCLA ASFALTICA	$ 137.45	m2	10.83	$ 1,489.04
INSPECCCIÓN RUTINARIA UNA VEZ AL AÑO	$ 18,000.00	Inspección	0.083	$ 1,500.00
Total por mes				**$ 2,989.04**

TOTAL PER MONTH : **$ 75,798 MP = $ 6,890 USD**

Results

Mayor maintenance cost

Actividades de mantenimiento mayor	Unidad	P.U.	Cantidad	Importe
FRESADO DE CARPETA ASFALTICA CON ESPESOR DE 3 CM	m3	$ 285.31	173.58	$ 49,525
CONSTRUCCIÓN DE CARPETA SMA DE 3 CM DE ESPESOR, CON ASFALTO MODIFICADO	m3	$ 2,617.40	173.58	$ 454,328
SUSTITUCION DE APOYOS DE NEOPRENO (INCLUYE GATEO)	Pza.	$ 6,918.40	192	$ 1,328,333
PROTECCION ANTICORROSIVA DEL PUENTE	Lote	$ 656,448.00	1	$ 656,448
SUSTITUCION DE ANODOS DE PROTECCION CATODICA	Pza.	$ 18,730.00	46	$ 861,580
SUMINISTRO Y COLOCACION DE SEÑALAMIENTO VERTICAL	Pza.	$ 10,800.00	6	$ 64,800
REPARACION DE JUNTAS DE CALZADA DEL PUENTE	ml	$ 2,572.00	264	$ 679,008
REPARACION DEL PARAPETO DEL PUENTE	ml	$ 145.00	1052	$ 152,540
REPARACION ACCESOS AL PUENTE	Lote	$ 74,300.00	2	$ 148,600
INYECCIÓN DE GRIETAS EN LOSA DE CONCRETO				
Total				**$ 4,395,162**

TOTAL : **$ 4,395,162 MP = $ 399,560 USD**

Annual investment to present costs

Year	Investment	Maintenance		Total
		Mainor	Mayor	
0	2,041,134			2,041,134
1		82,680		82,680
2		82,680		82,680
3		82,680		82,680
4		82,680		82,680
5		82,680		82,680
6		82,680		82,680
7		82,680		82,680
8		82,680		82,680
9		82,680		82,680
10		82,680		82,680
11		82,680		82,680
12		82,680	399,560	482,240
13		82,680		82,680
14		82,680		82,680
15		82,680		82,680
16		82,680		82,680
17		82,680		82,680
18		82,680		82,680
19		82,680		82,680
20		82,680		82,680
21		82,680		82,680
22		82,680		82,680
23		82,680		82,680
24		82,680		82,680
25		82,680	399,560	482,240
26		82,680		82,680
27		82,680		82,680
28		82,680		82,680
29		82,680		82,680
30		82,680		82,680
TOTAL (US Dollars)				5,320,654

Conclusions

- The structural condition of the bridge, although rated 3, it requires urgent repair maintenance to reach acceptable Resistance State Limits.

- Little corrosion damage. Rehabilitate cathodic protection system in some piles and thermal-spray with Zn on metallic structure to increase protection.

- According to present traffic, structural reinforcement of 25 and 38 m spans is necessary; but sufficient to a 30 years extended life.

- Maintenance and rehabilitation costs may allow a relatively low toll fee with a reasonable income during the useful life of the project.

Thank You
Gracias