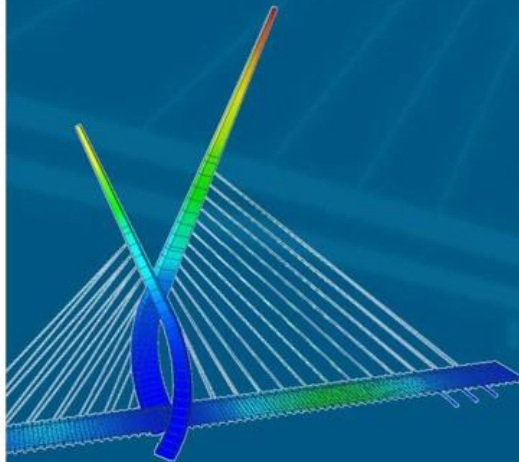


Pondasi Jembatan Berbentang Panjang

[Seminar “Peran Geoteknik Dalam Pembangunan
Infrastruktur Transportasi di Kalimantan”, Banjarmasin
1 Oktober 2016]

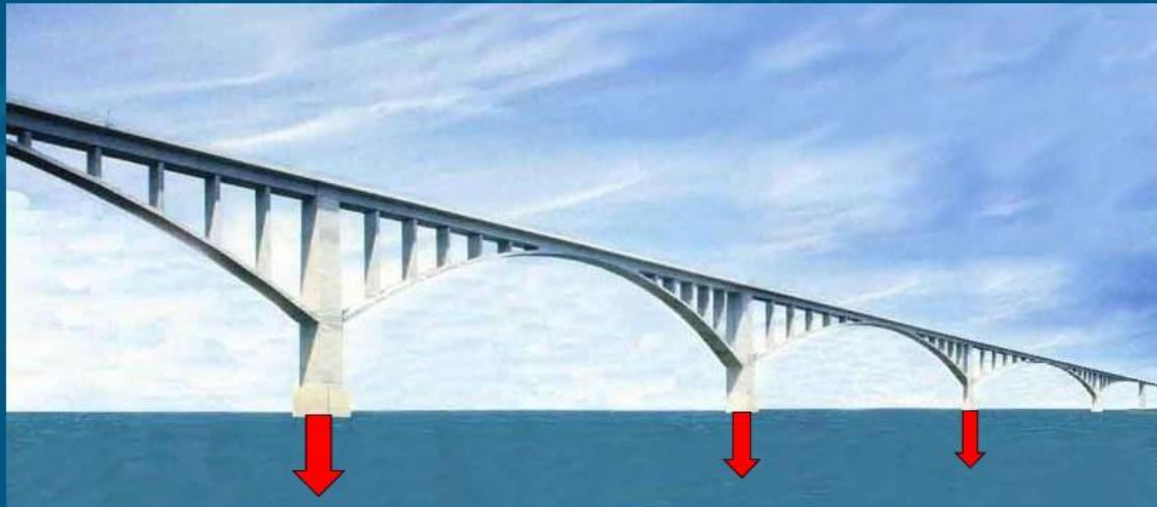
FX Supartono & Team
PT Partono Fondas Engineering Consultant

Seringkali dikatakan bahwa sejarah perkembangan pembangunan jembatan dapat menggambarkan perkembangan budaya manusia dari jaman dulu hingga sekarang. Oleh sebab itu desain sebuah jembatan harus dapat memenuhi berbagai aspek yang setidaknya meliputi sebagai berikut:

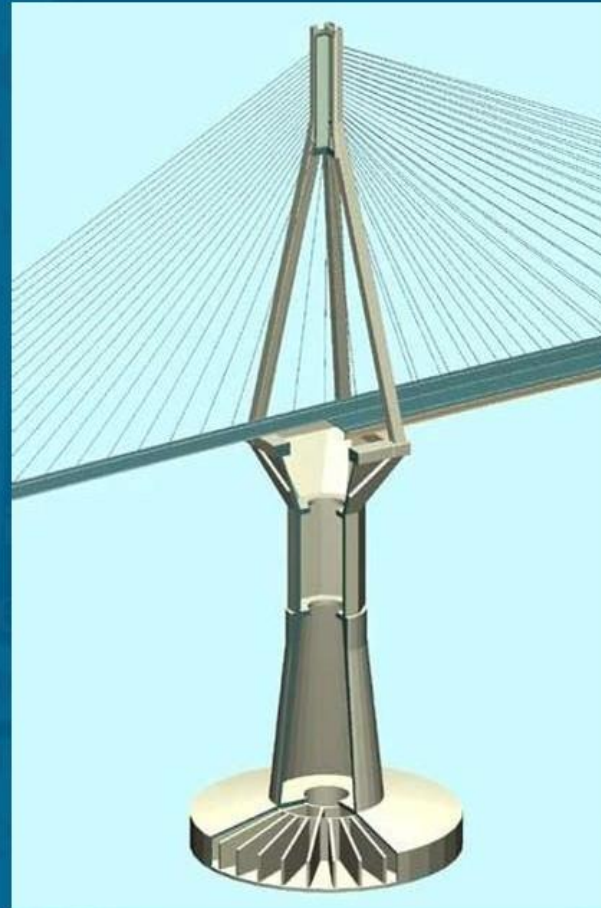


- Keamanan & stabilitas struktur**
- Kelayanan bagi pengguna**
- Economis**
- Estetika**
- Keawetan jangka panjang**
- Metode konstruksi yang sesuai dengan kondisi lapangan**
- Mudah untuk pemeliharaan**
- Dampak yang minimal terhadap lingkungan**

Dalam pada itu, pondasi merupakan bagian yang sangat vital dalam suatu struktur jembatan, yang berfungsi sebagai tumpuan jembatan dan sekaligus meneruskan beban yang disalurkan dari struktur atas jembatan ke tanah dasar, baik itu di darat, di sungai ataupun di dasar laut.



Berbeda dengan struktur bawah bangunan gedung, struktur bawah jembatan pada umumnya mempunyai bagian di atas tanah dasar yang cukup tinggi dan seringkali “langsing”, sehingga memerlukan kekakuan dan stabilitas yang prima dalam menerima beban dari struktur atas.



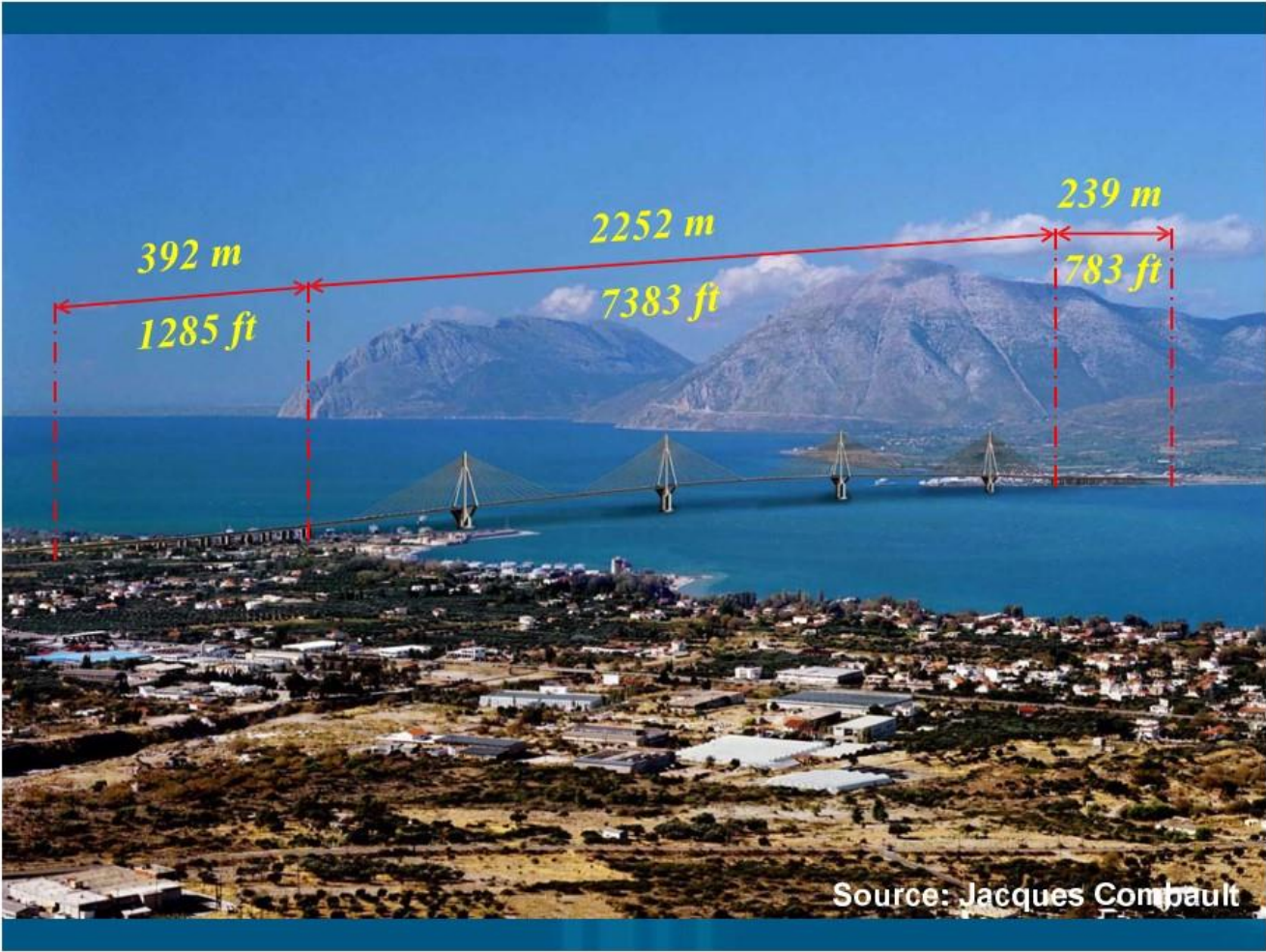
Ada berbagai faktor teknis yang mempengaruhi desain pondasi jembatan berbentang panjang, antara lain:

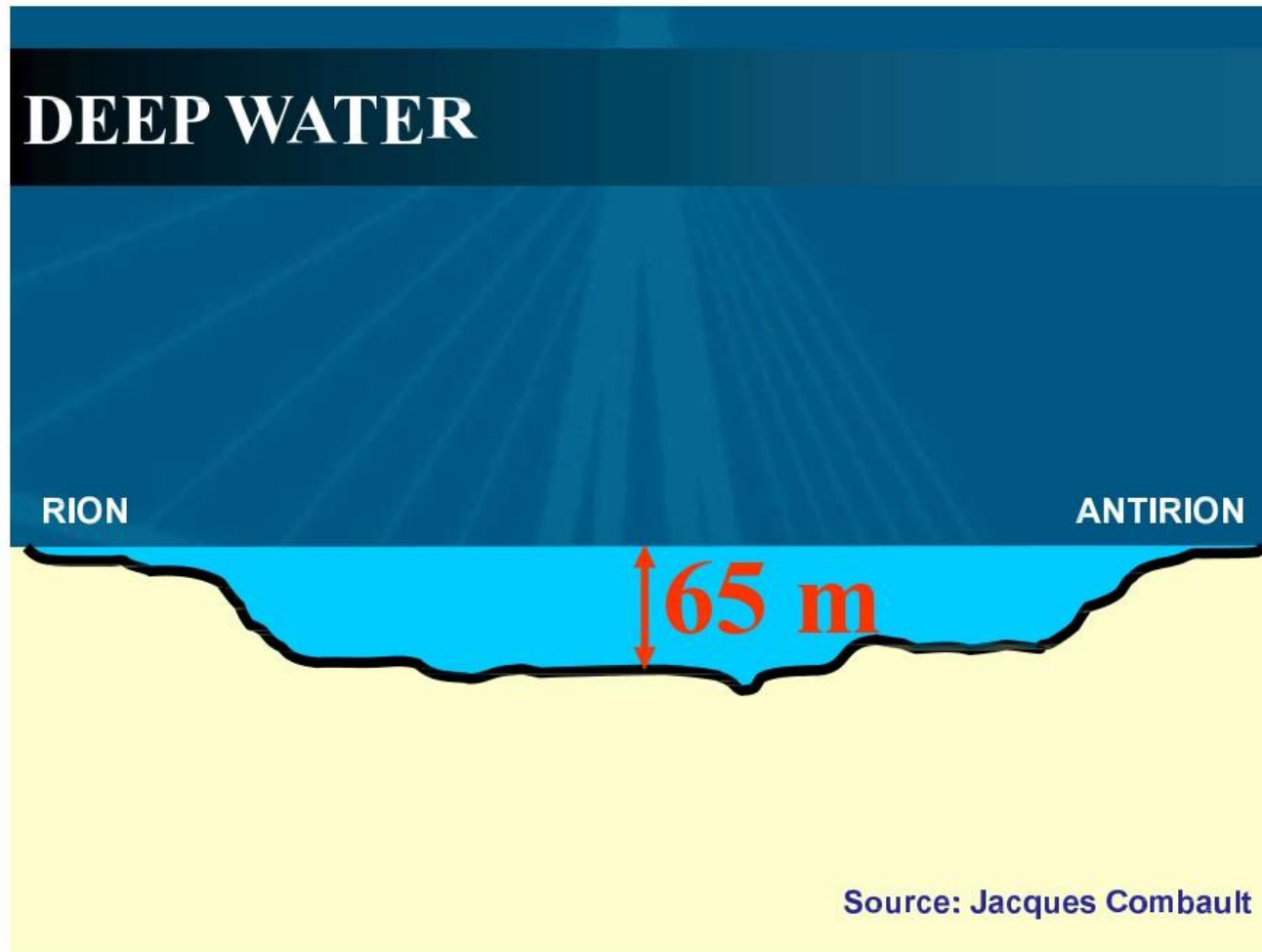
- Kondisi geoteknik / daya dukung tanah
- Kedalaman tanah dasar di bawah permukaan air (bila di sungai atau di laut)
- Kondisi kegempaan di lokasi jembatan
- Interaksi pergerakan kapal (ship impact), khususnya untuk daerah navigasi kapal-kapal besar

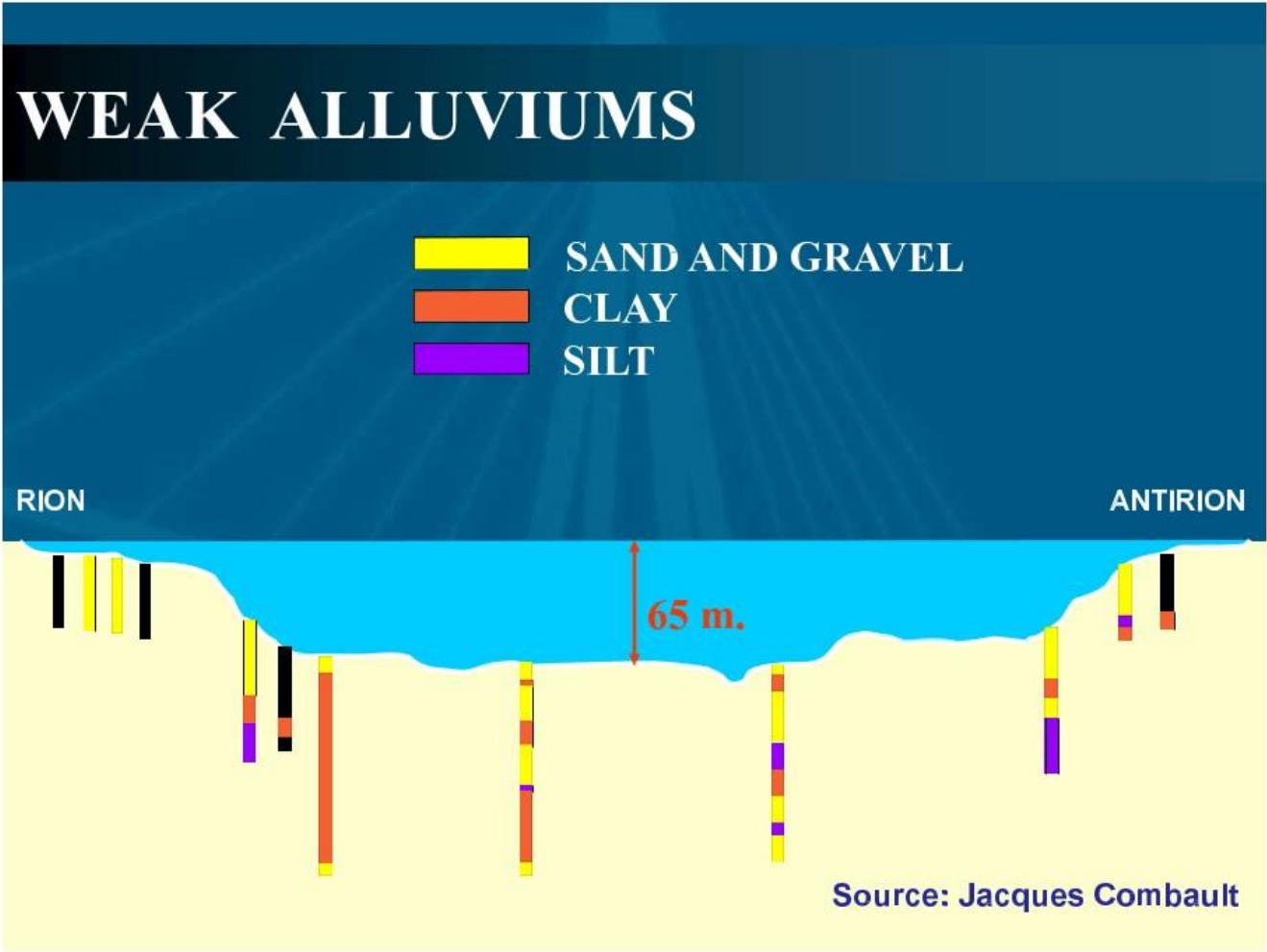


Case Study 1
Rion-Antirion Bridge

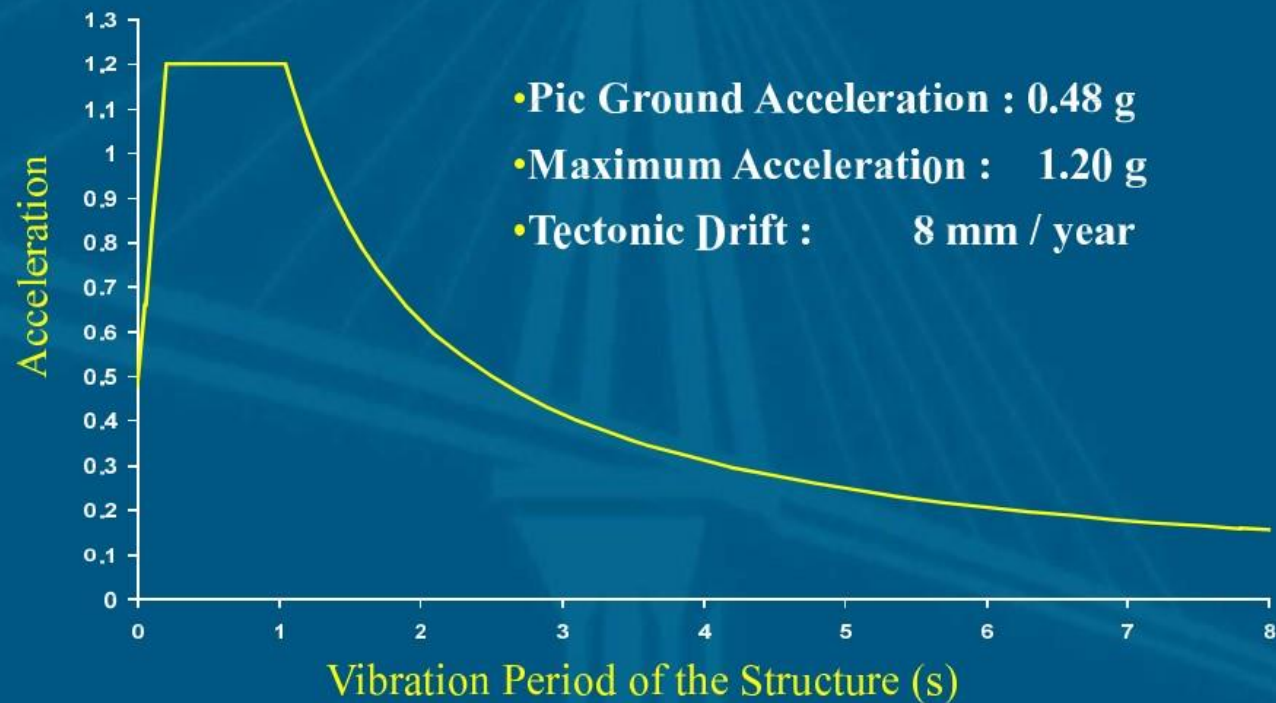


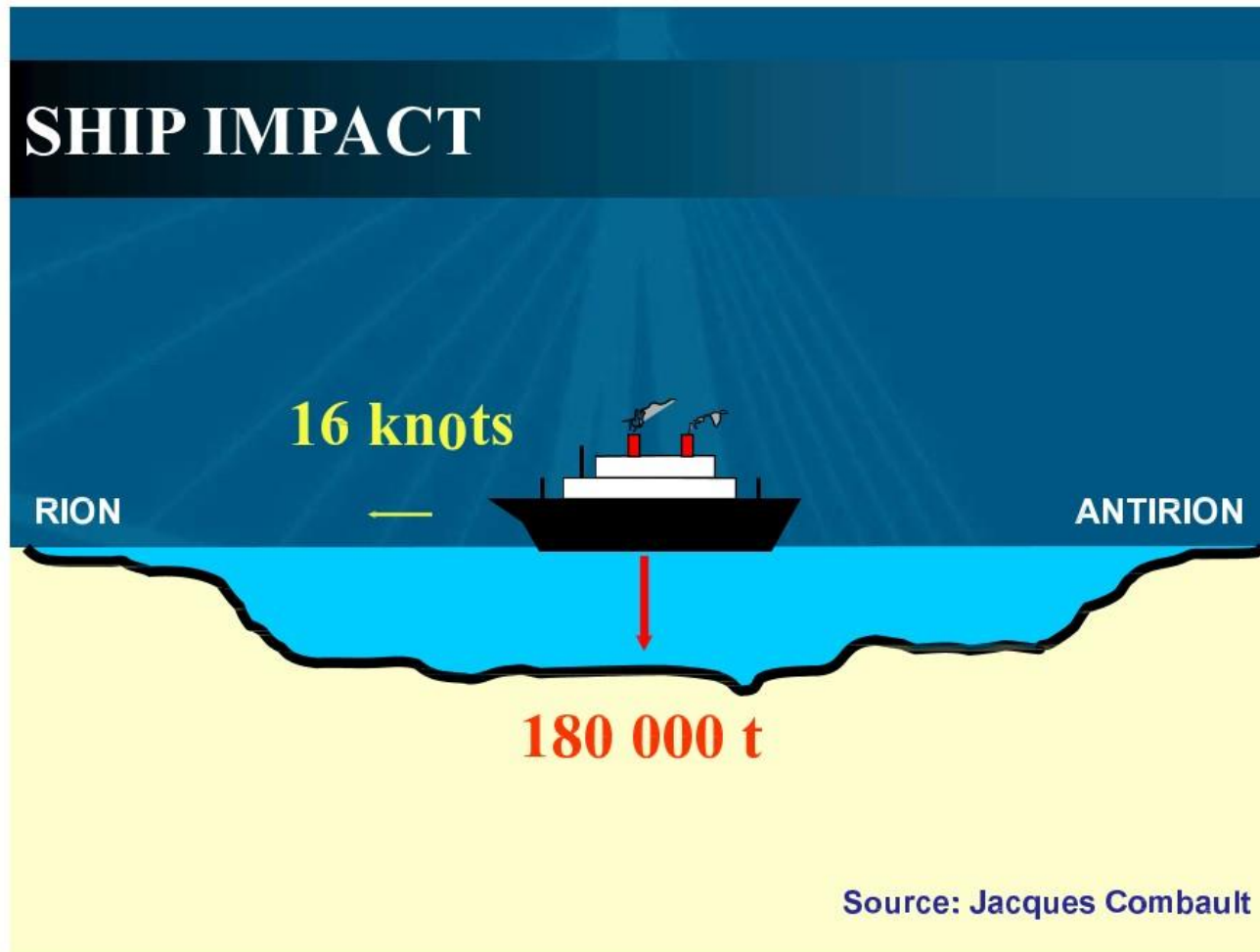




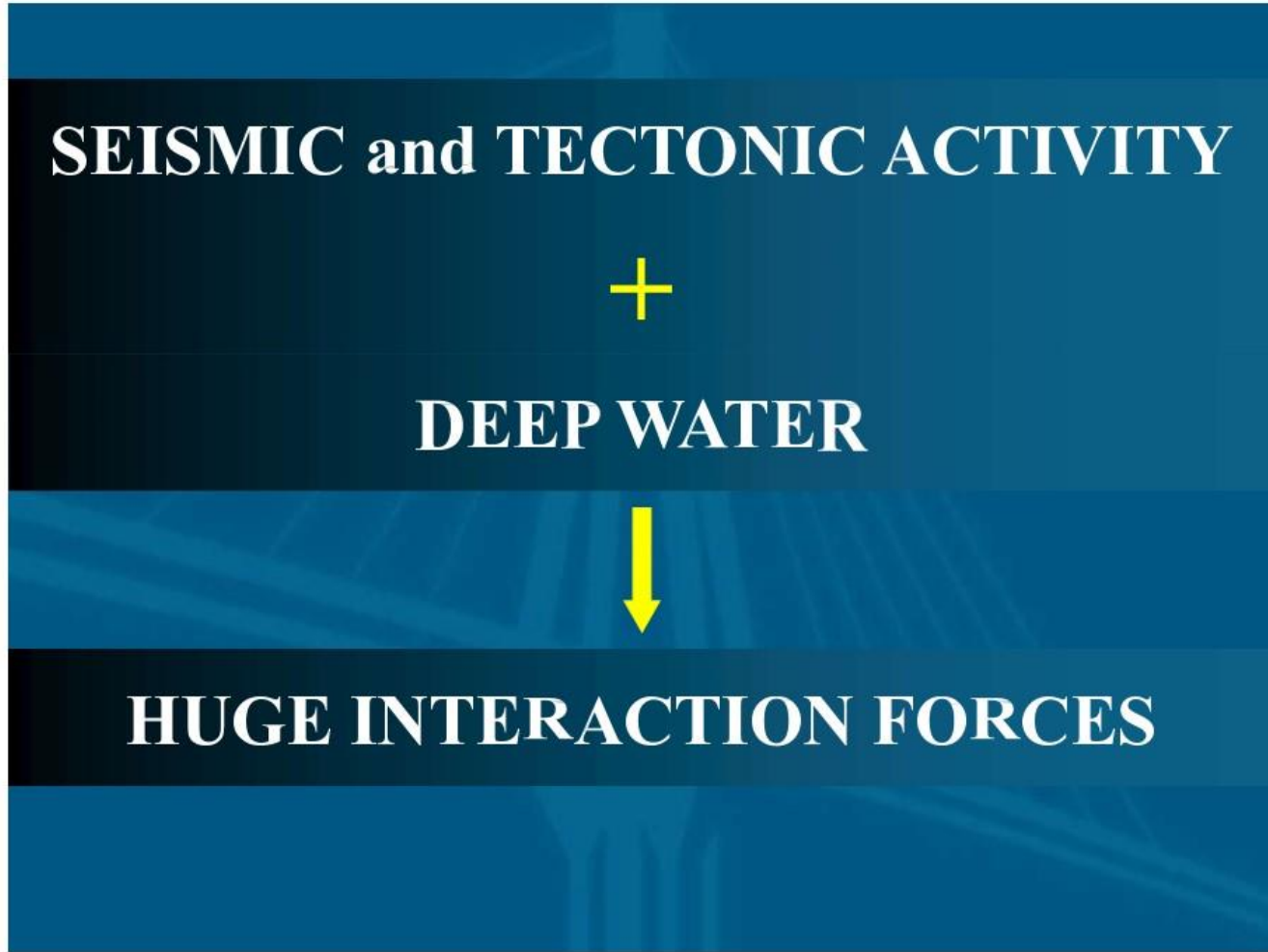


SEISMIC and TECTONIC ACTIVITY





**65 m WATER DEPTH
WEAK ALLUVIUMS
SEISMIC INTENSITY
TECTONIC ACTIVITY
SHIP IMPACT**



HUGE INTERACTION FORCES

+

WEAK ALLUVIUMS



WHAT ABOUT FOUNDATION ?

RION-ANTIRION Main Bridge

286

560

560

560

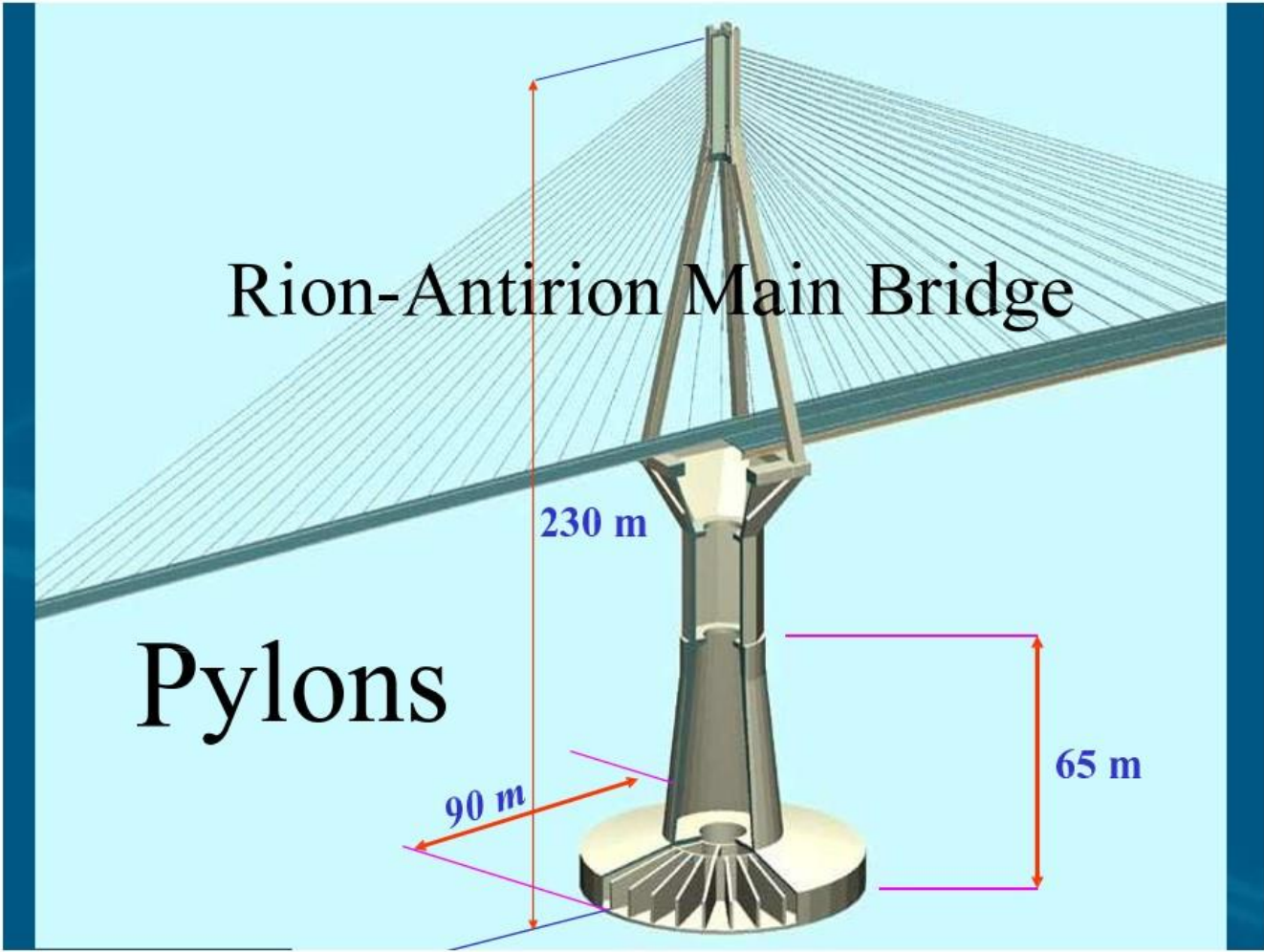
286

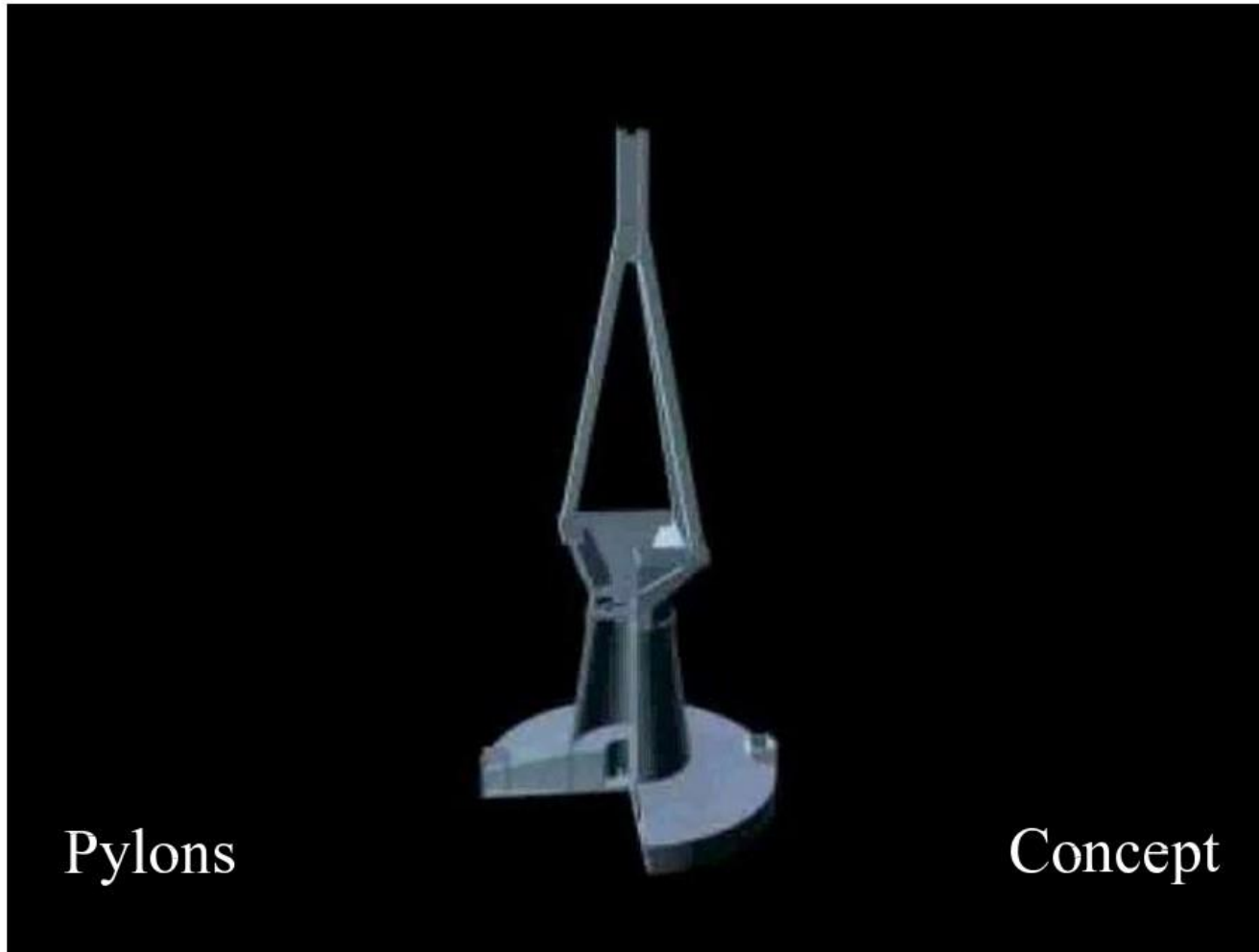
2252

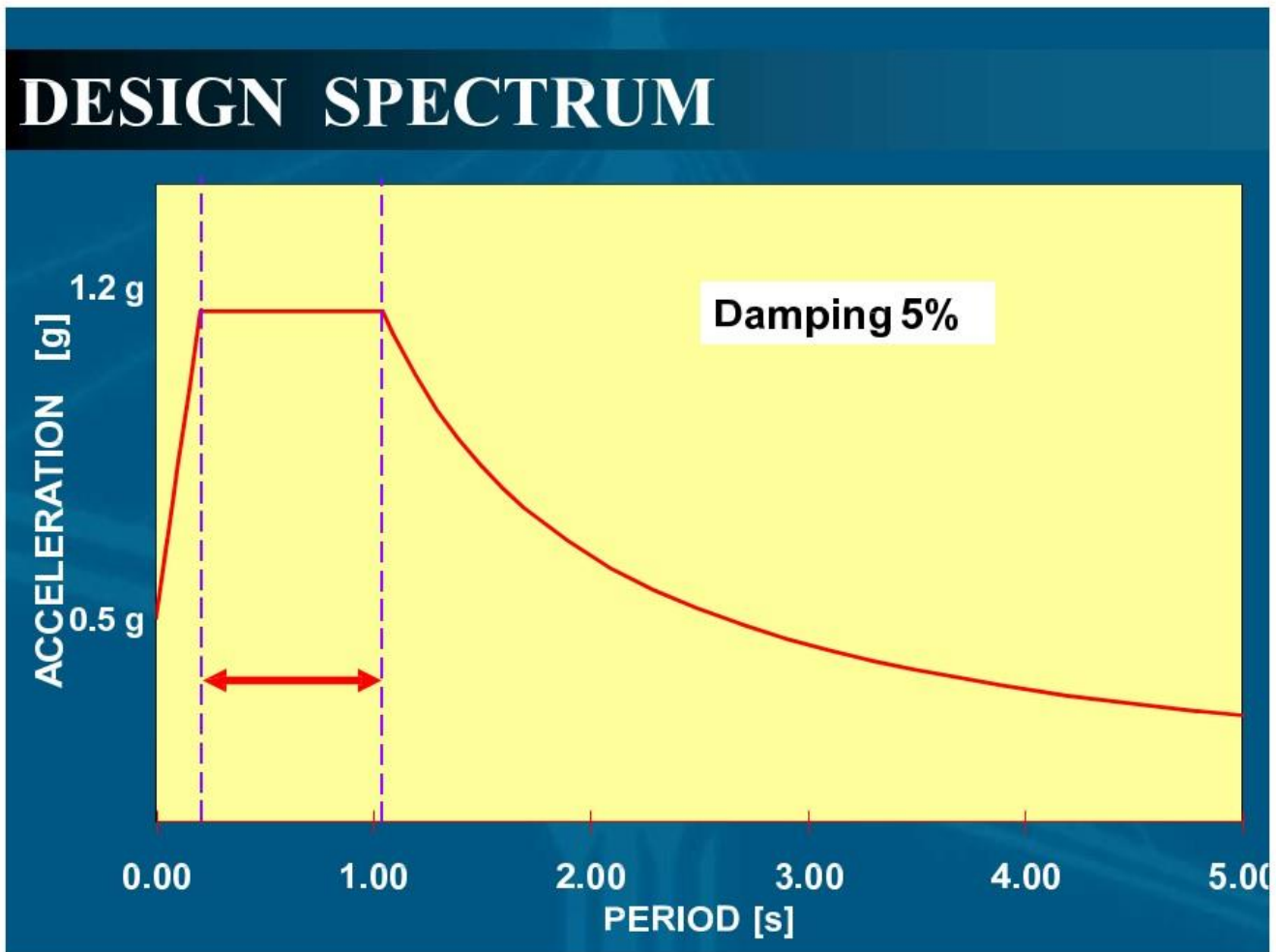


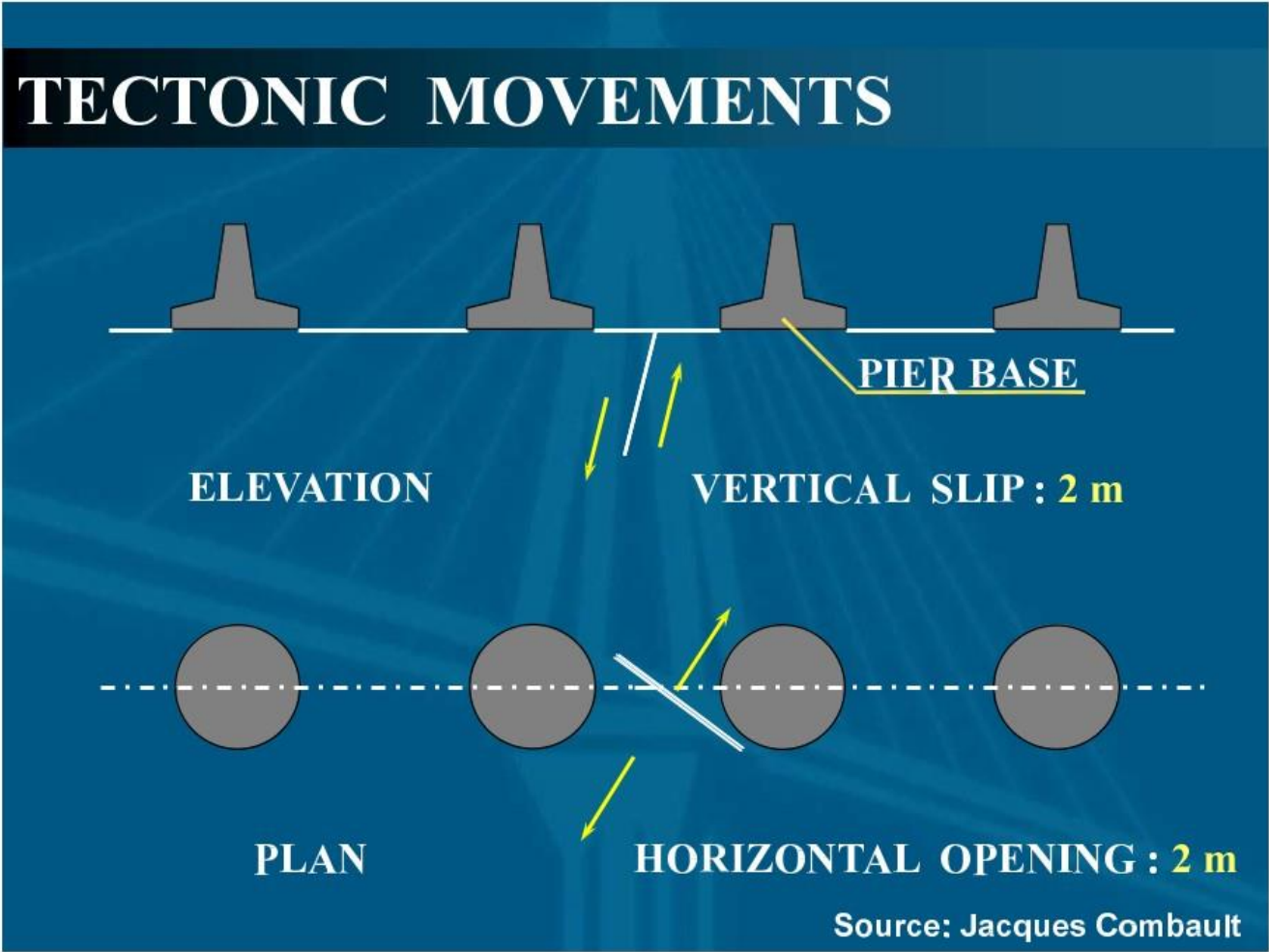






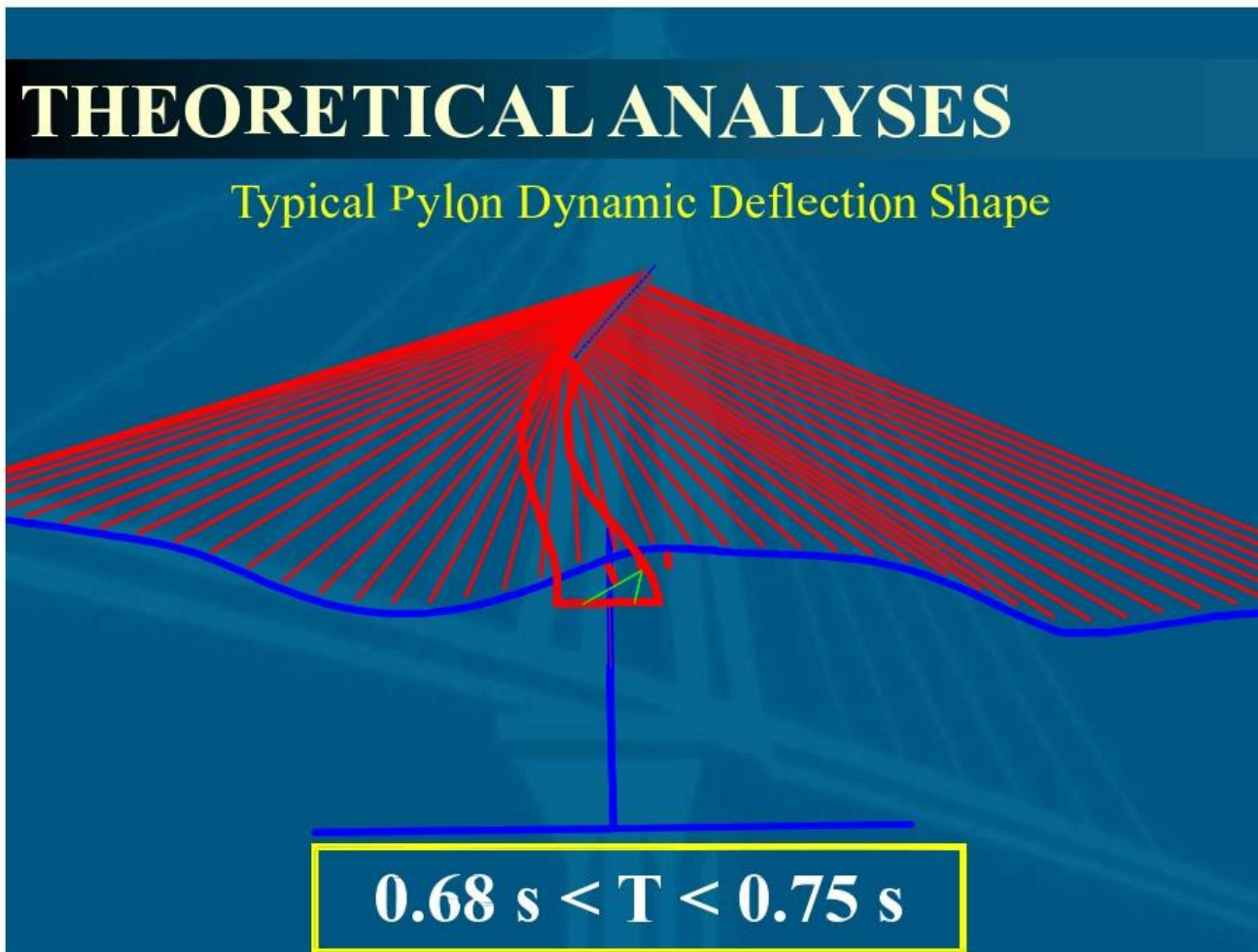


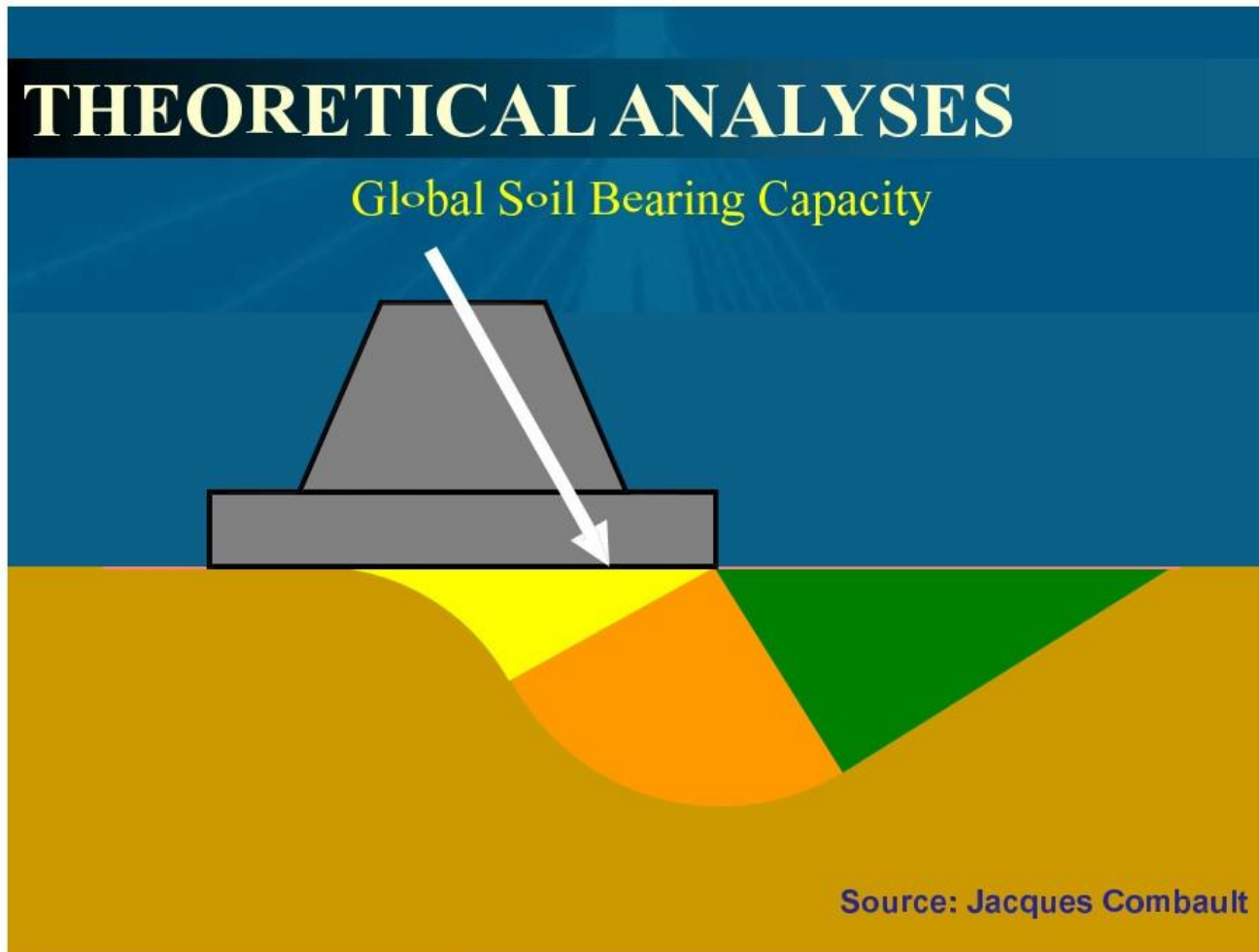


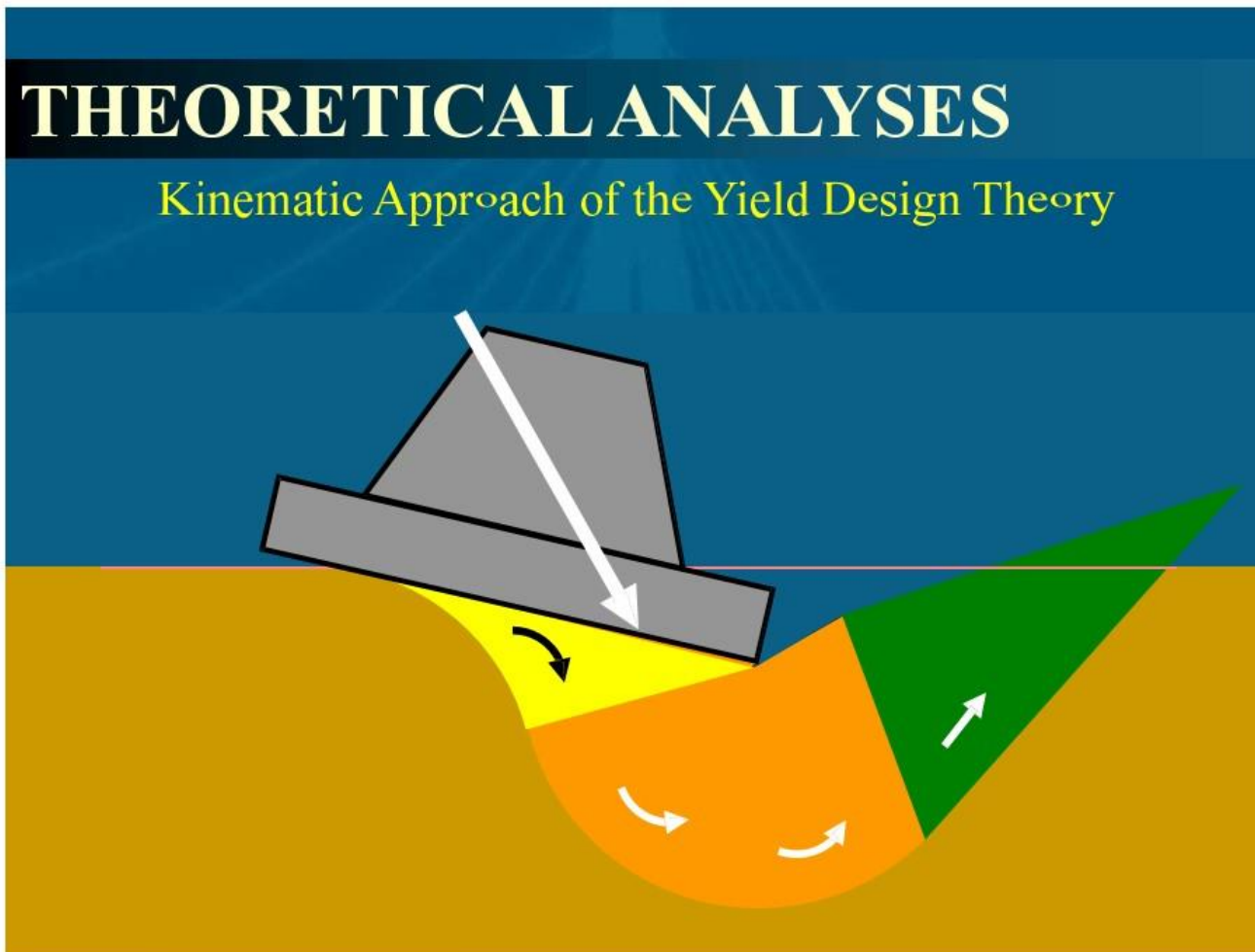


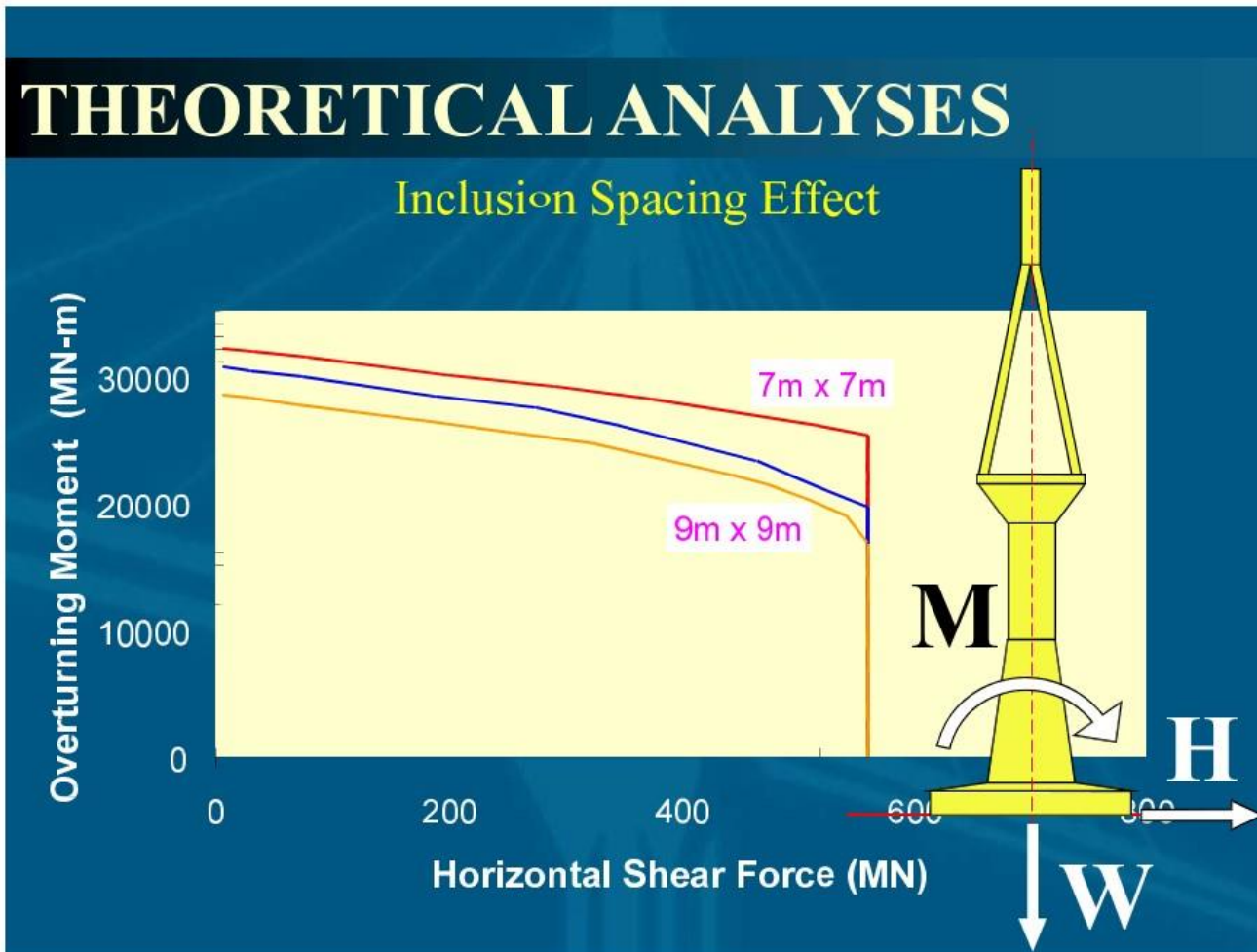


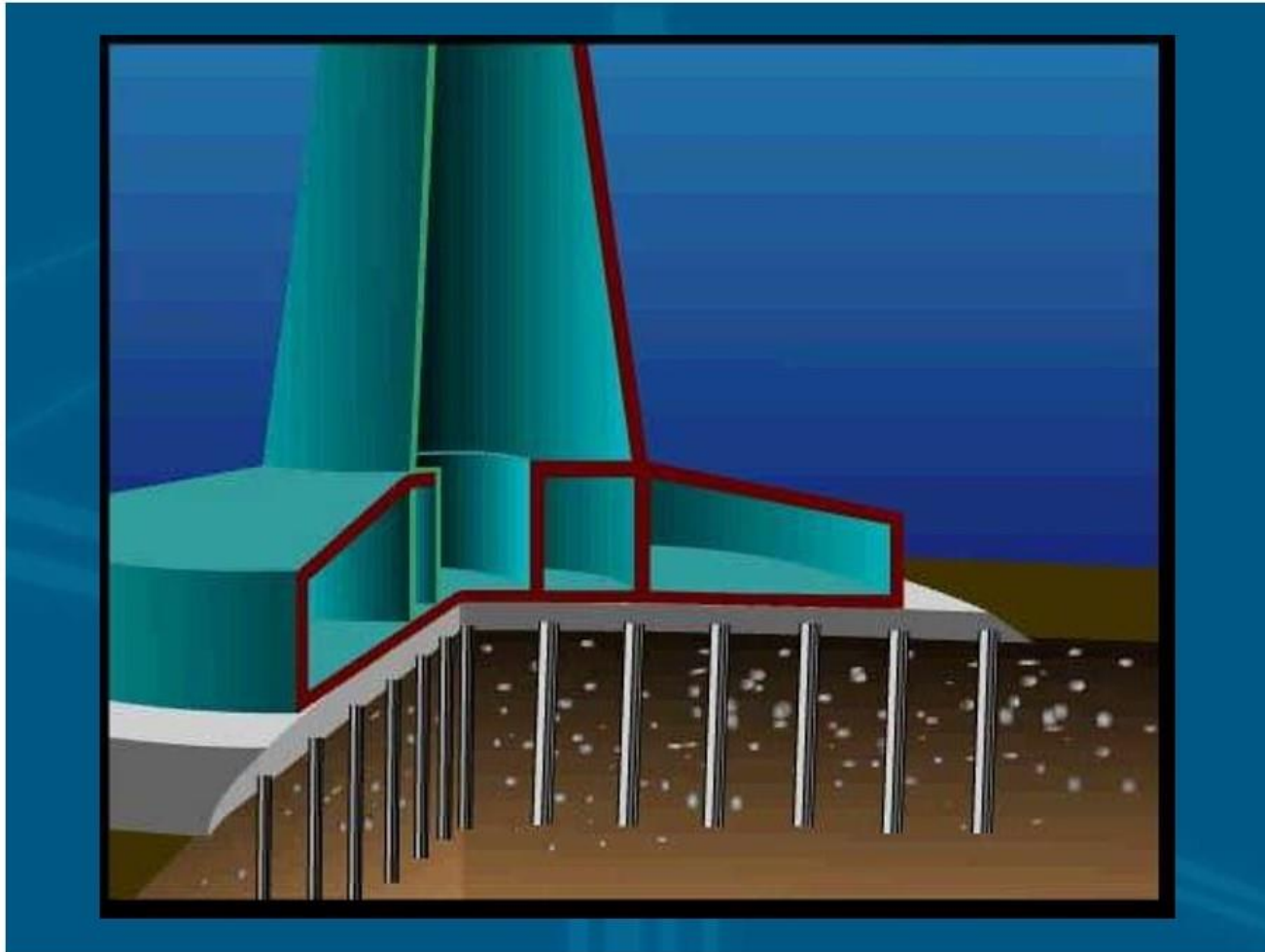
Seismic Evaluation on the Foundation

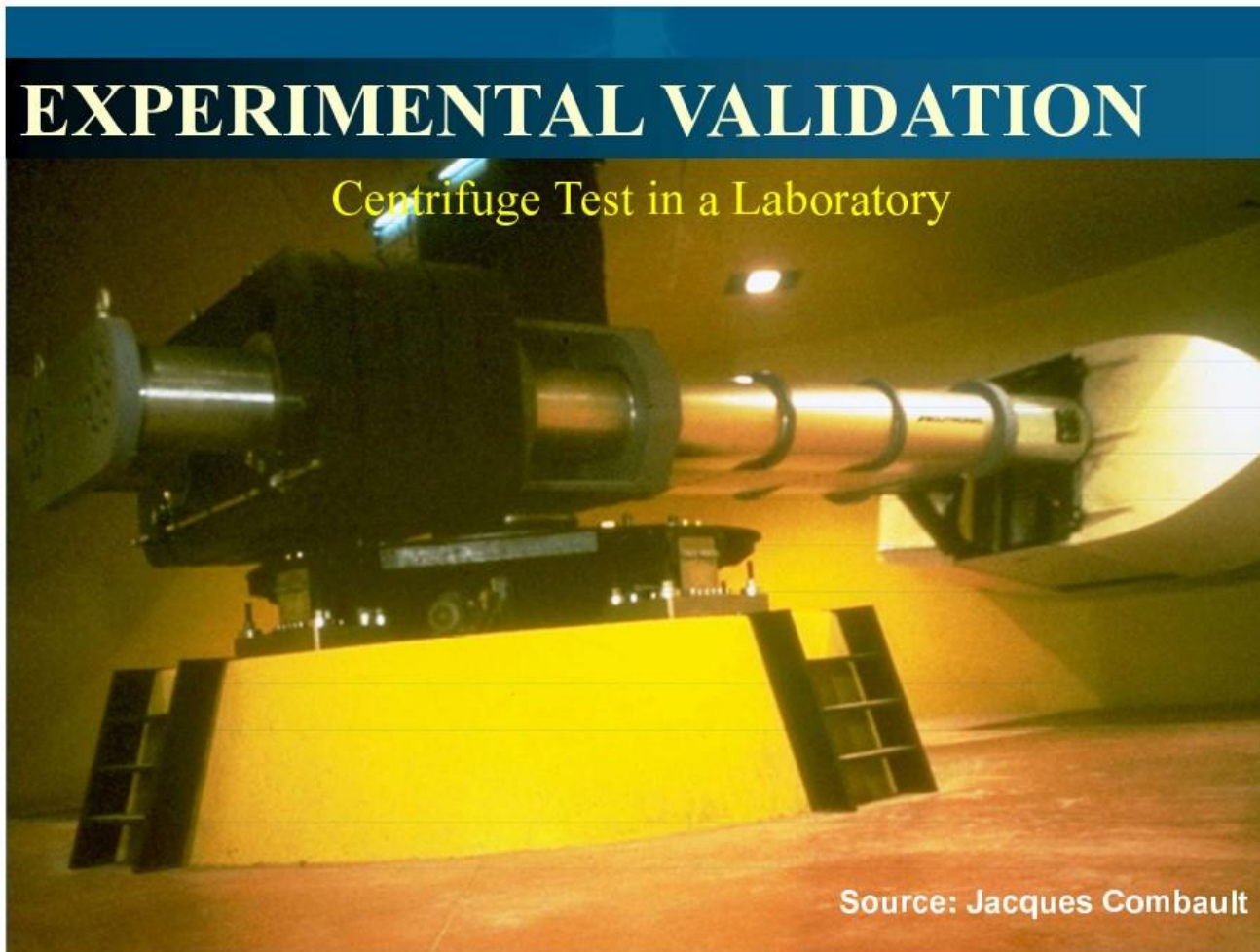


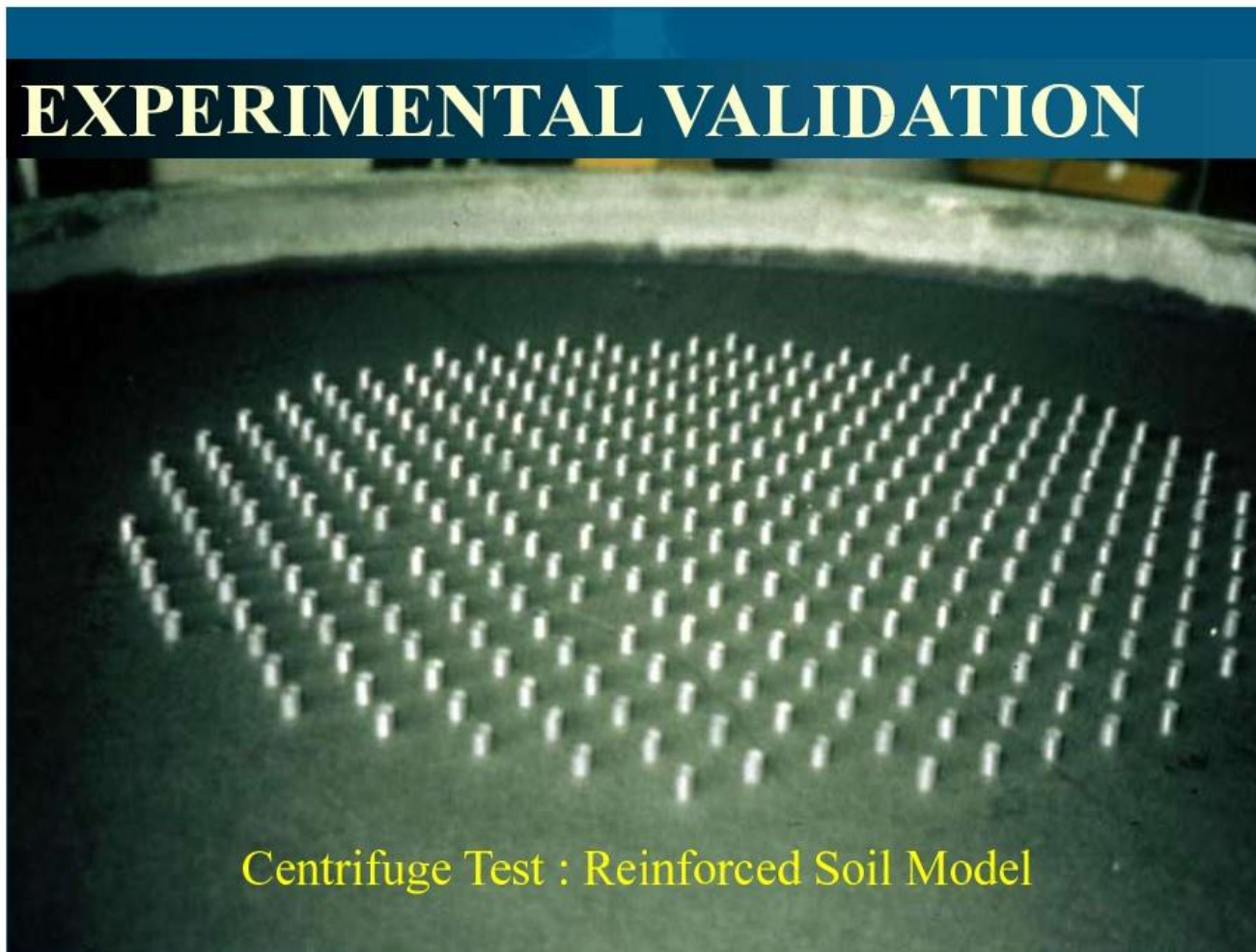


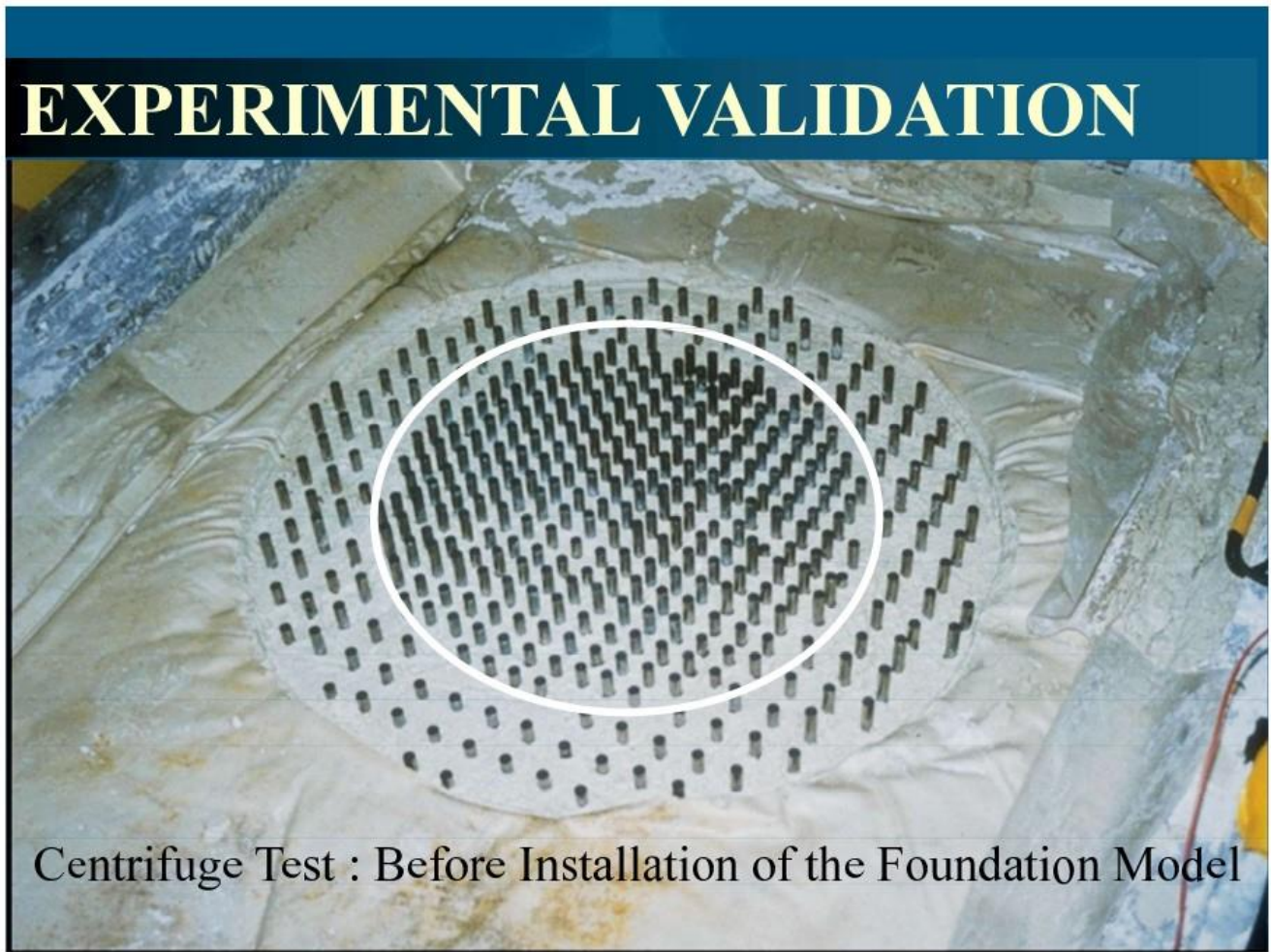








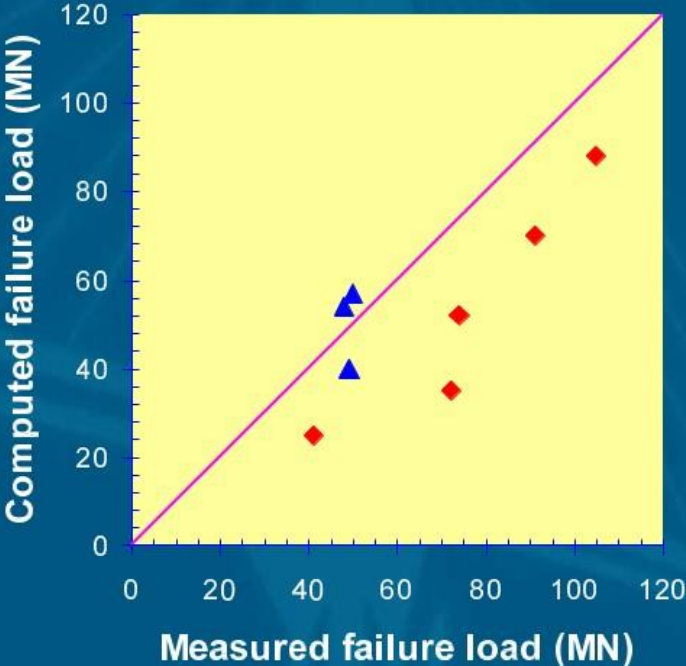




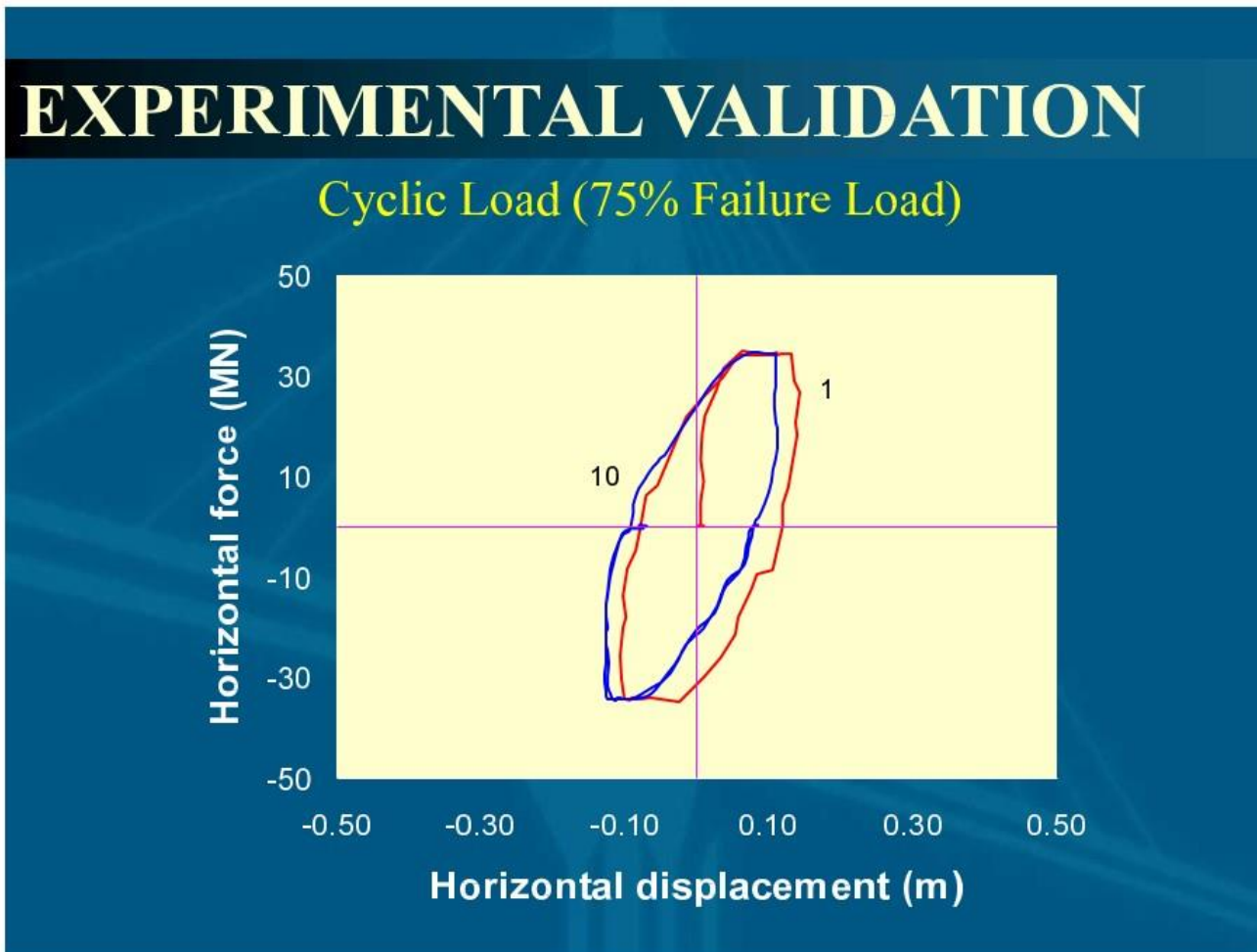


EXPERIMENTAL VALIDATION

Monotonic Failure Load



Source: Jacques Combault

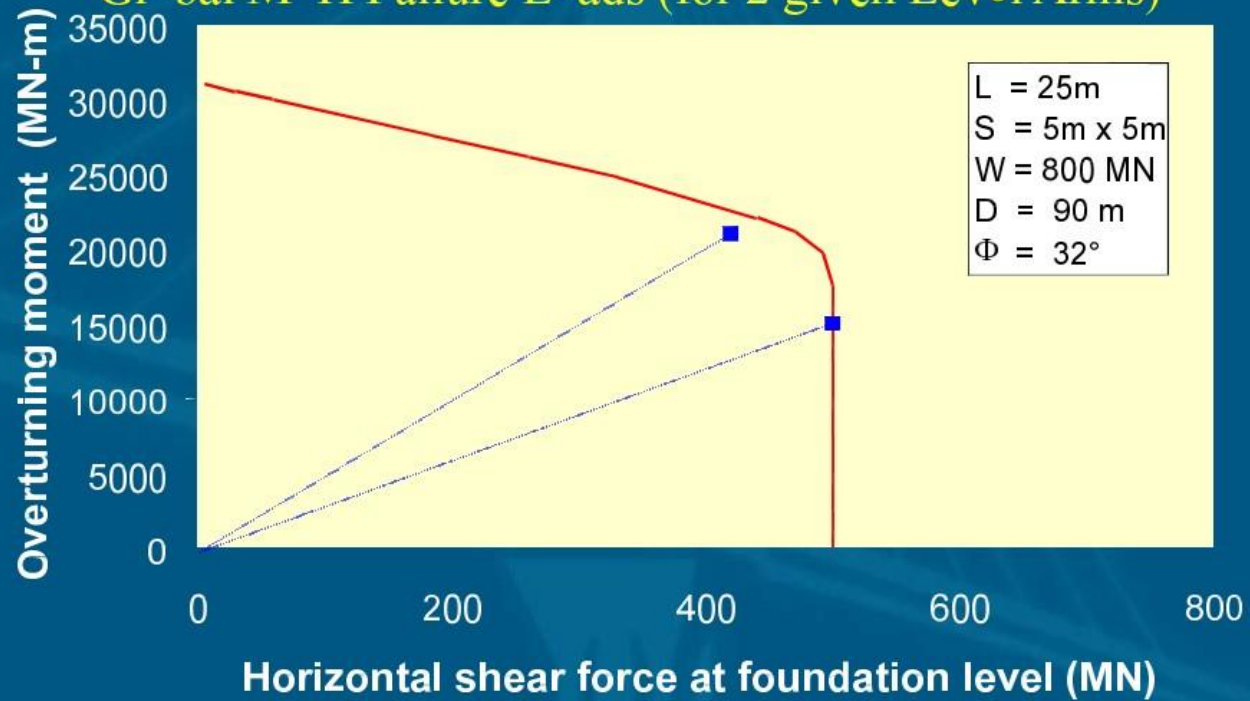


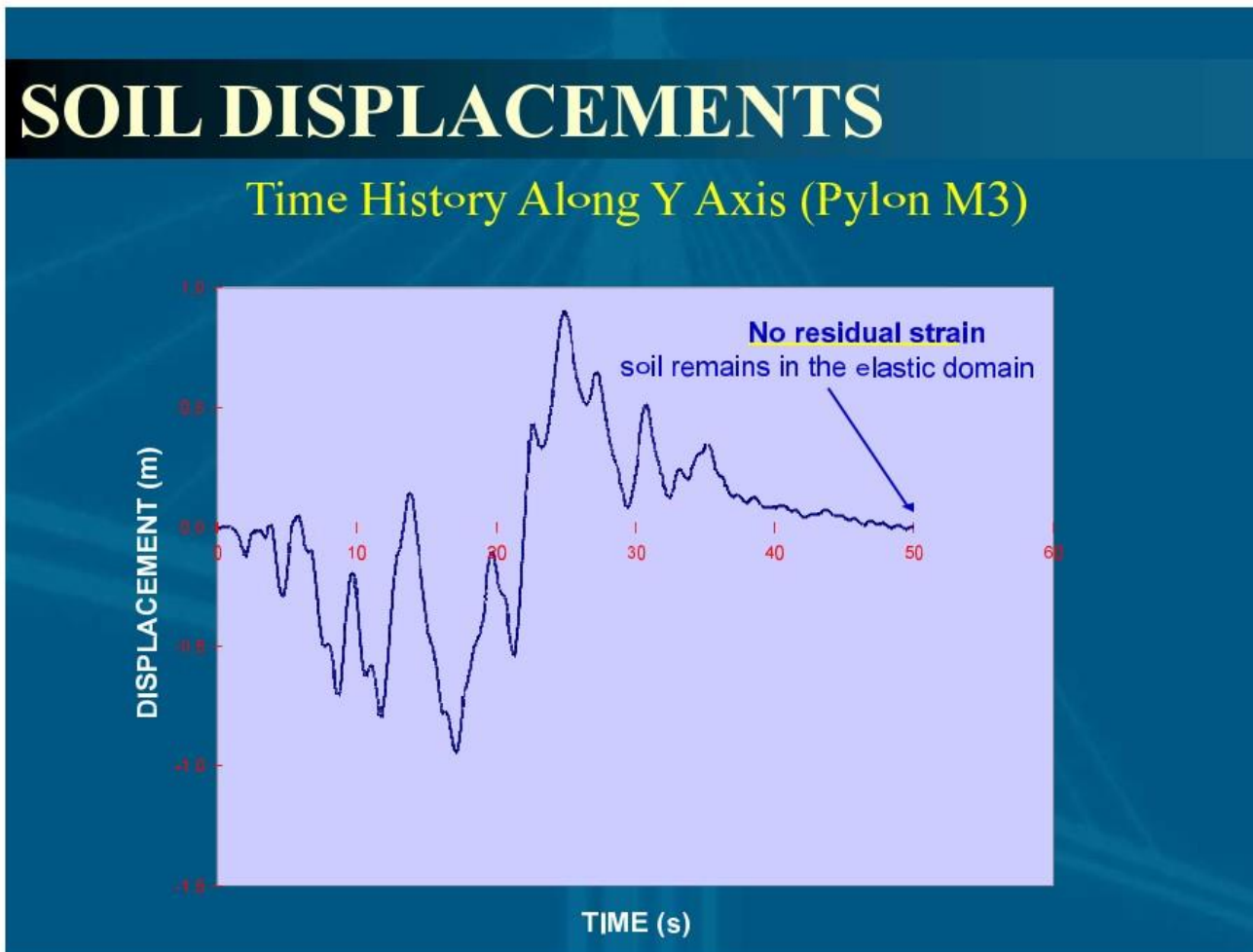
FINITE ELEMENT ANALYSES

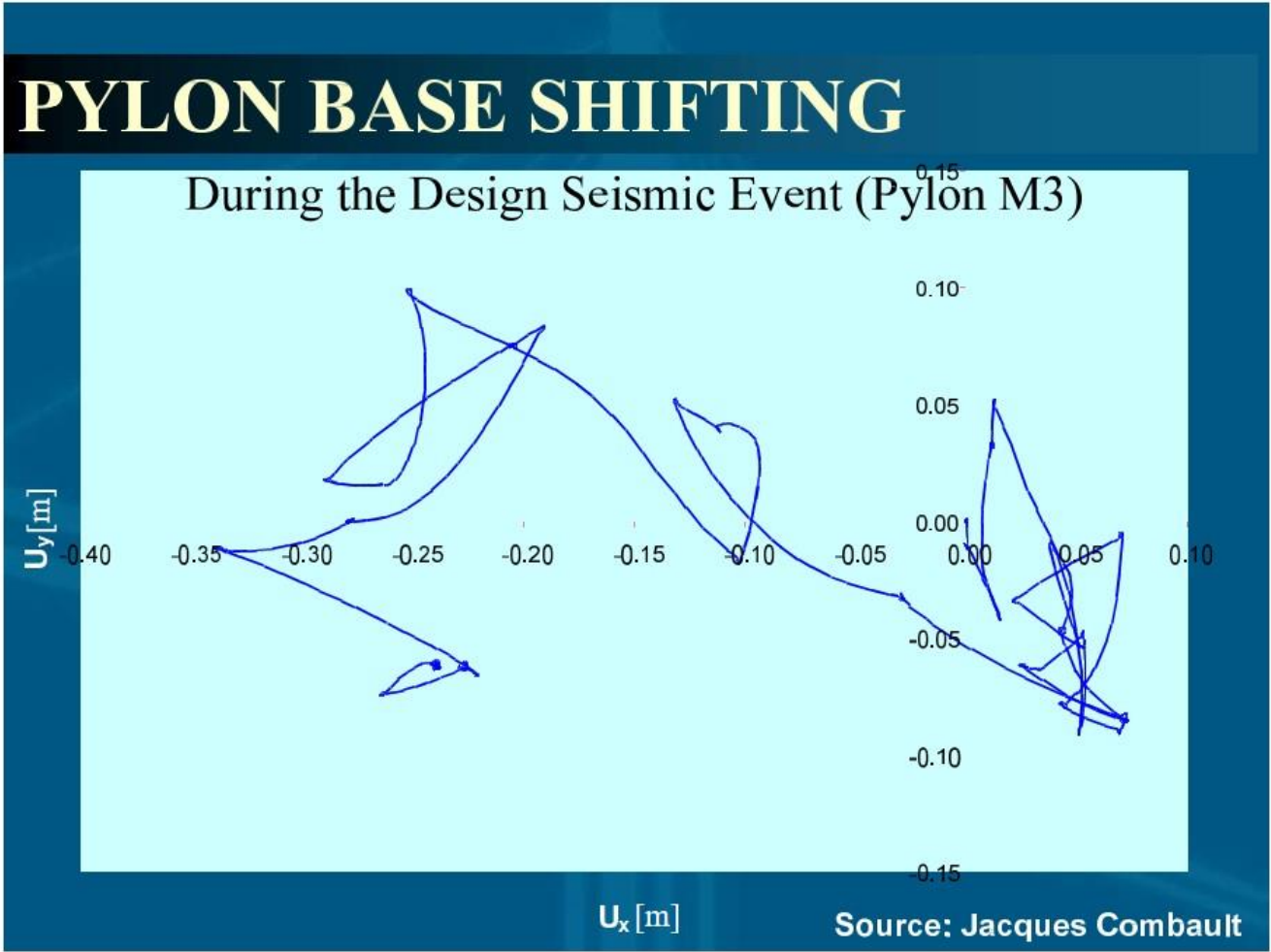
- **Soil**
 - **Continuum elements**
 - **Elastoplastic constitutive law**
- **Inclusions**
 - **Beam elements**
 - **Linear elastic** → Check on computed forces
- **Interface : Soil-Raft & Soil-Inclusions**
 - **Limited shear capacity**
 - **No tensile capacity (soil-raft)**

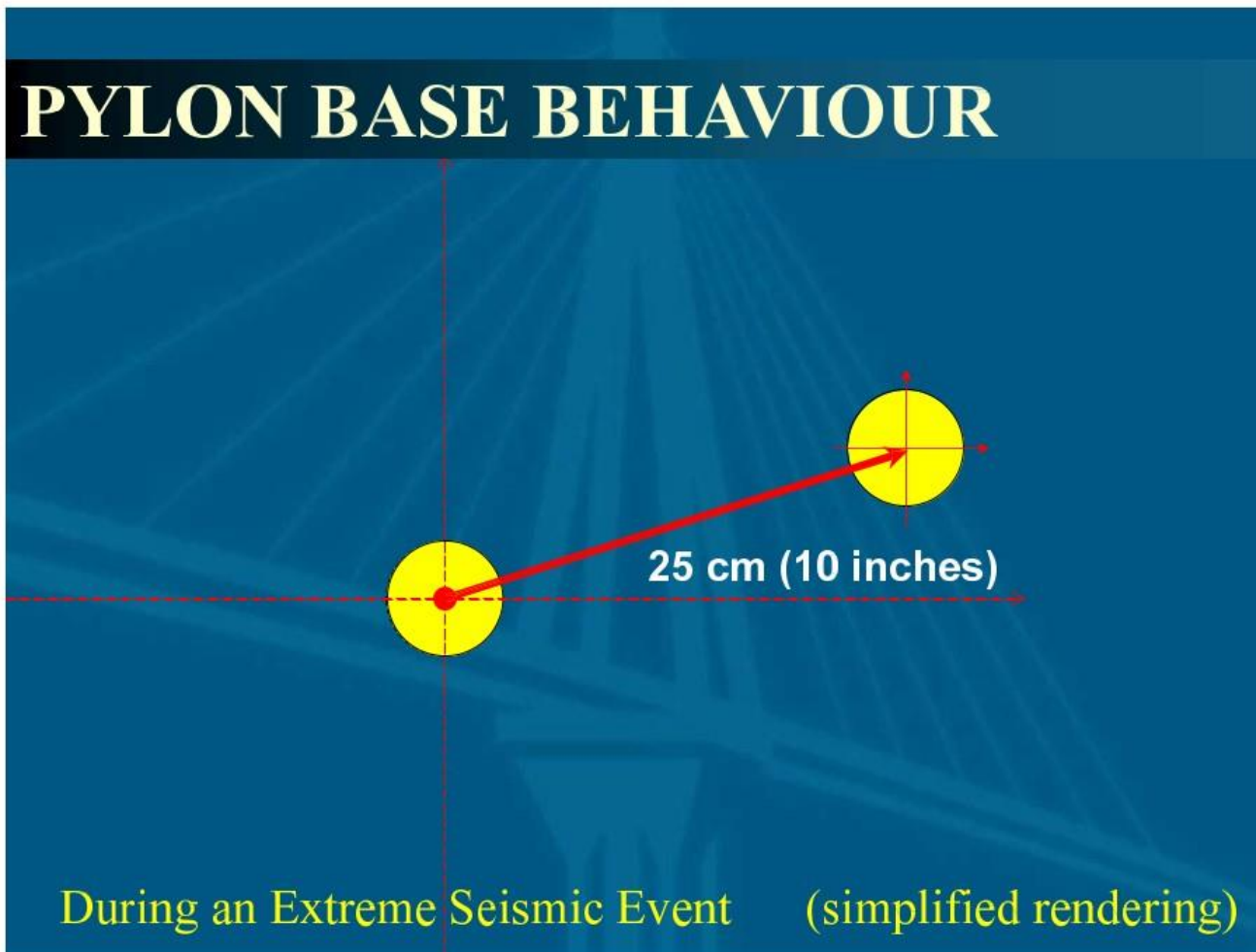
FINITE ELEMENT ANALYSES

Global M-H Failure Loads (for 2 given Level Arms)











Case Study 2

Sunda Strait Bridge

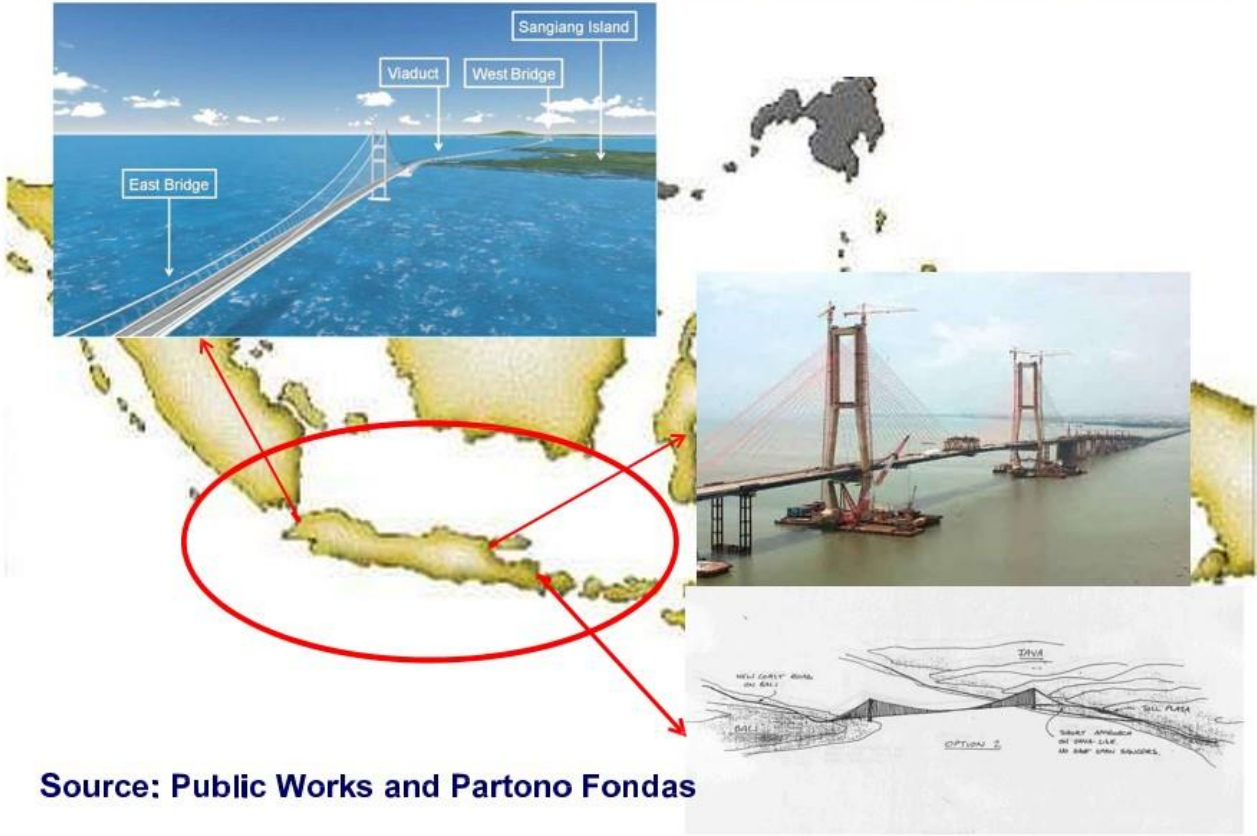
Sumatra – Jawa – Bali – Madura Link

42



Sumatra – Jawa – Bali – Madura Link

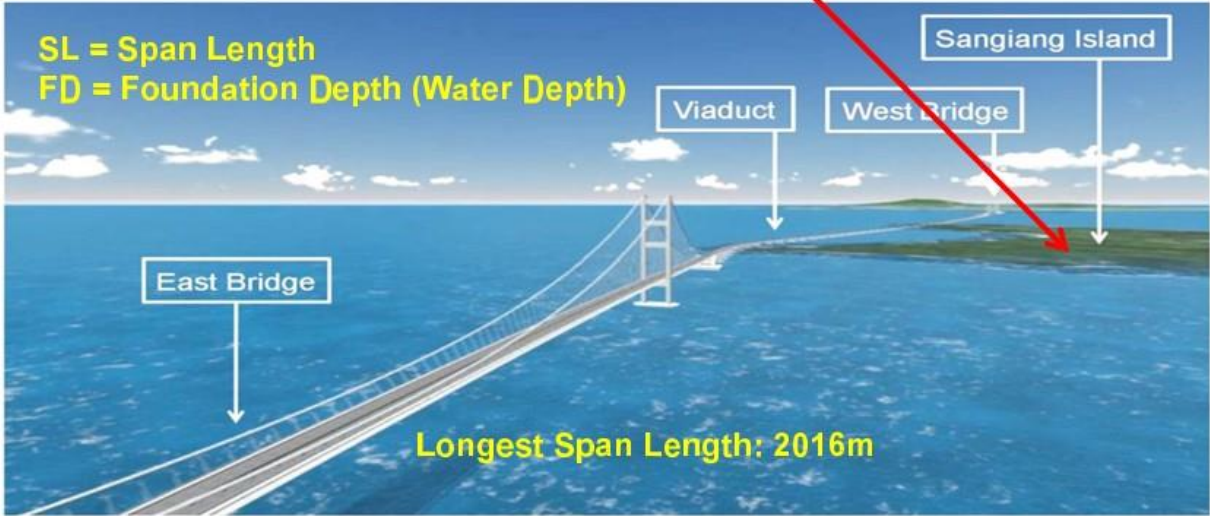
43



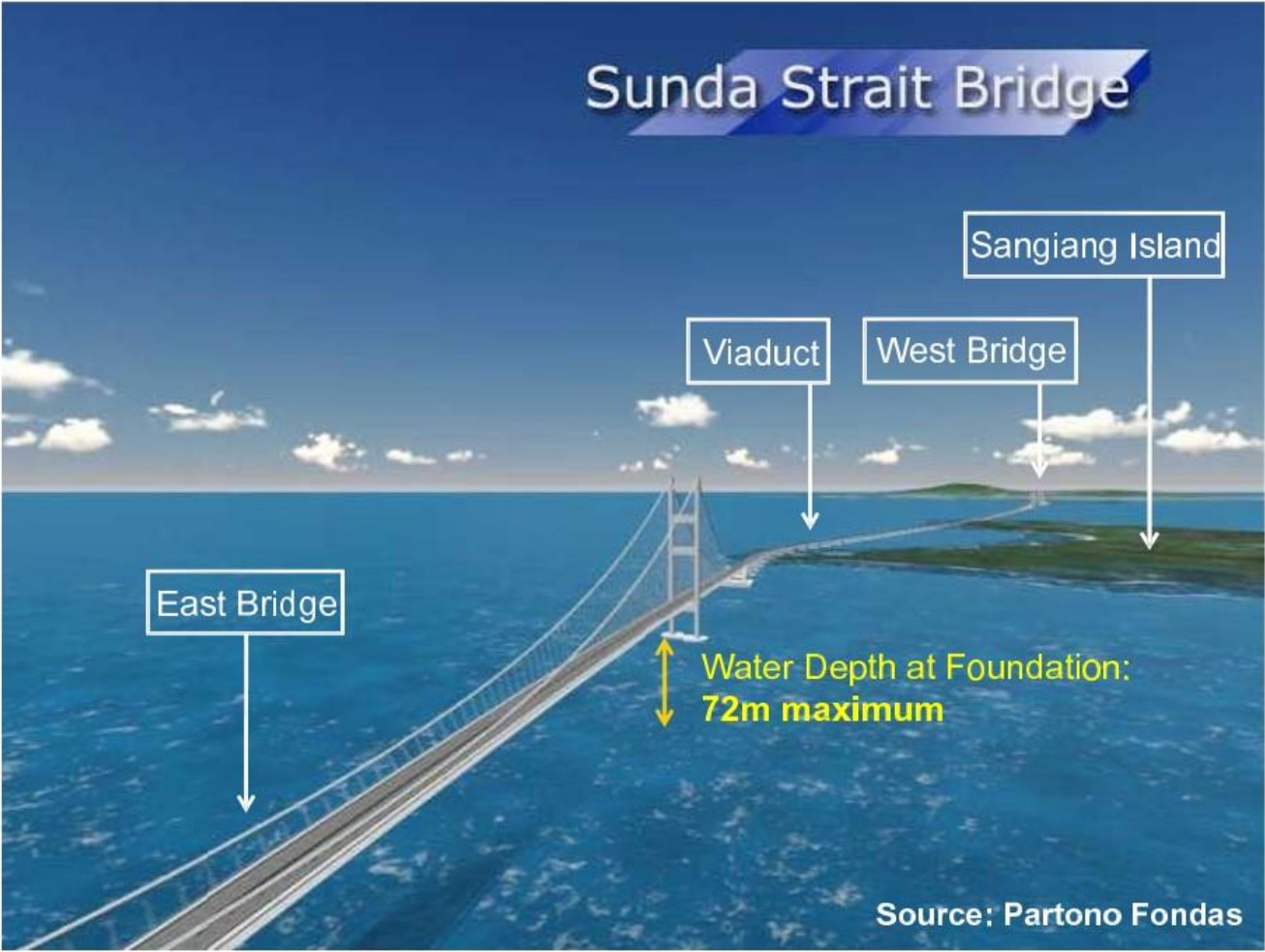
Source: Public Works and Partono Fondas

Sunda Strait Bridge

44



Source: Partono Fondas

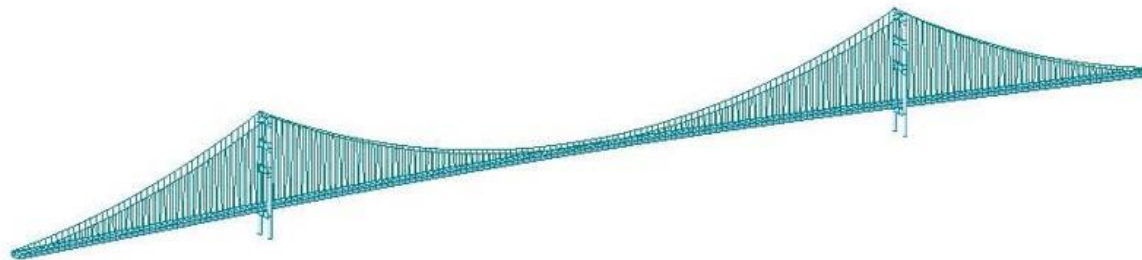




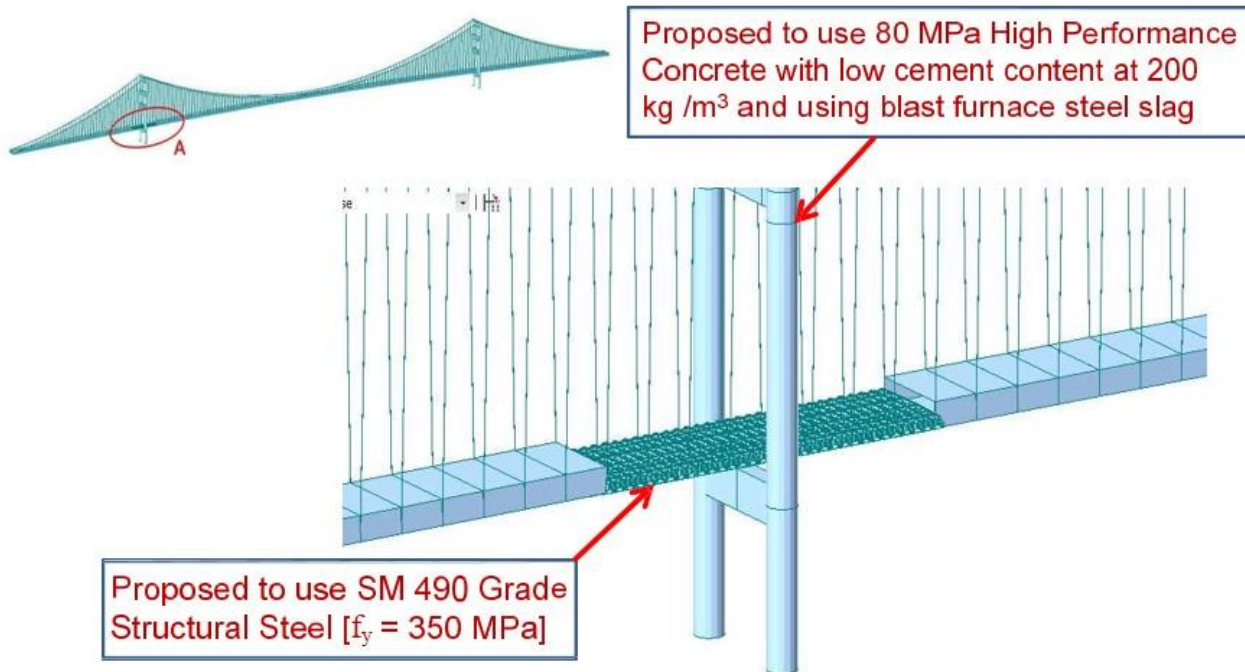
Structural Modeling of SSB using Midas Civil Software

Structural analysis of the ultra long-span bridges have been performed using **Midas Civil software by simulation in 3-D structural modeling. Here below is the bridge model performed using **Midas Civil**.**

PostCS



For more detailed structural design check of the girder elements, a Partial Grid Model has been developed in the Midas Civil modeling.



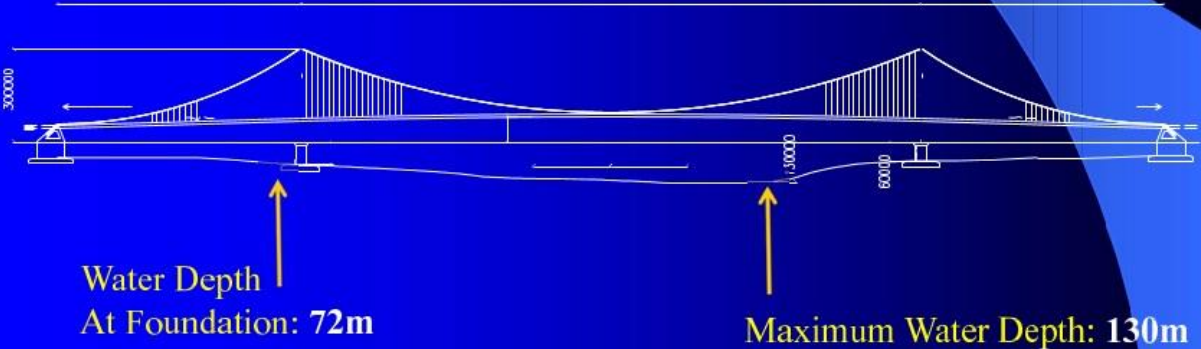


Proposed
Ultra Long-Span
Bridge Foundation

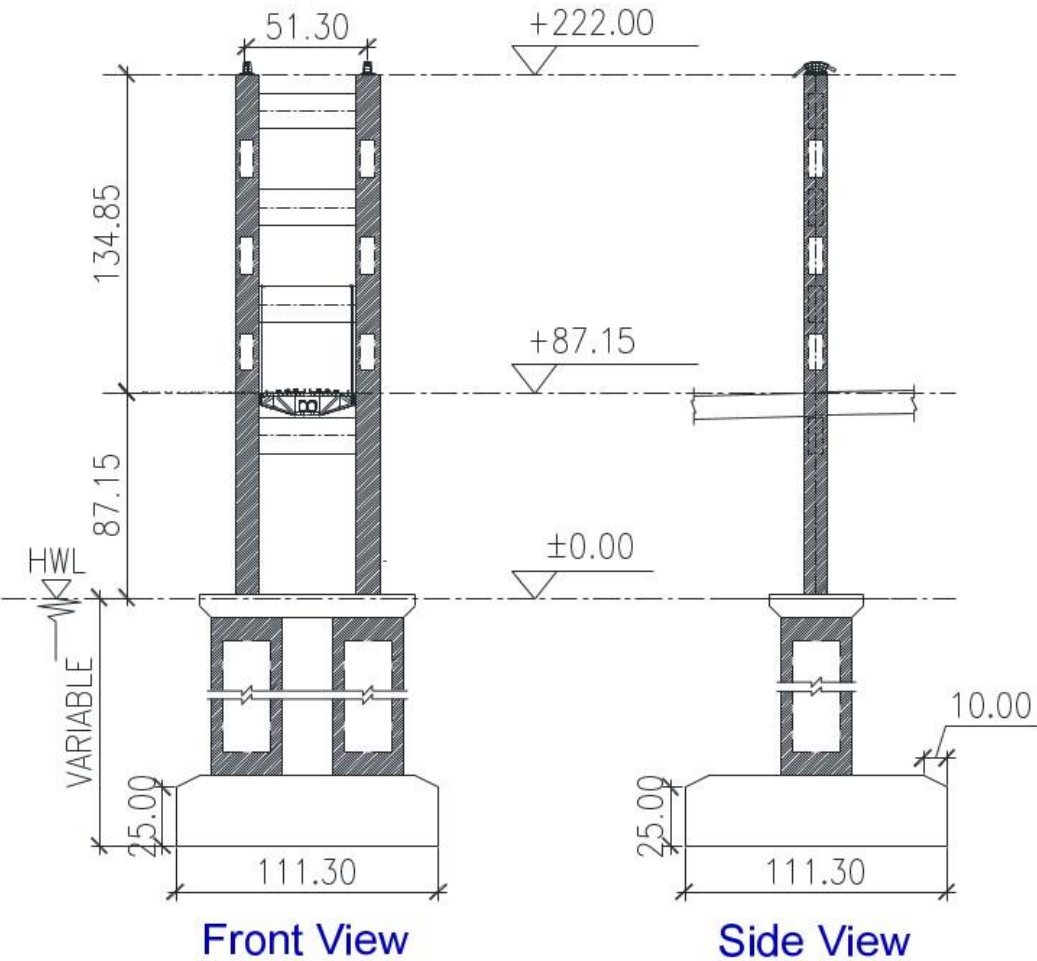


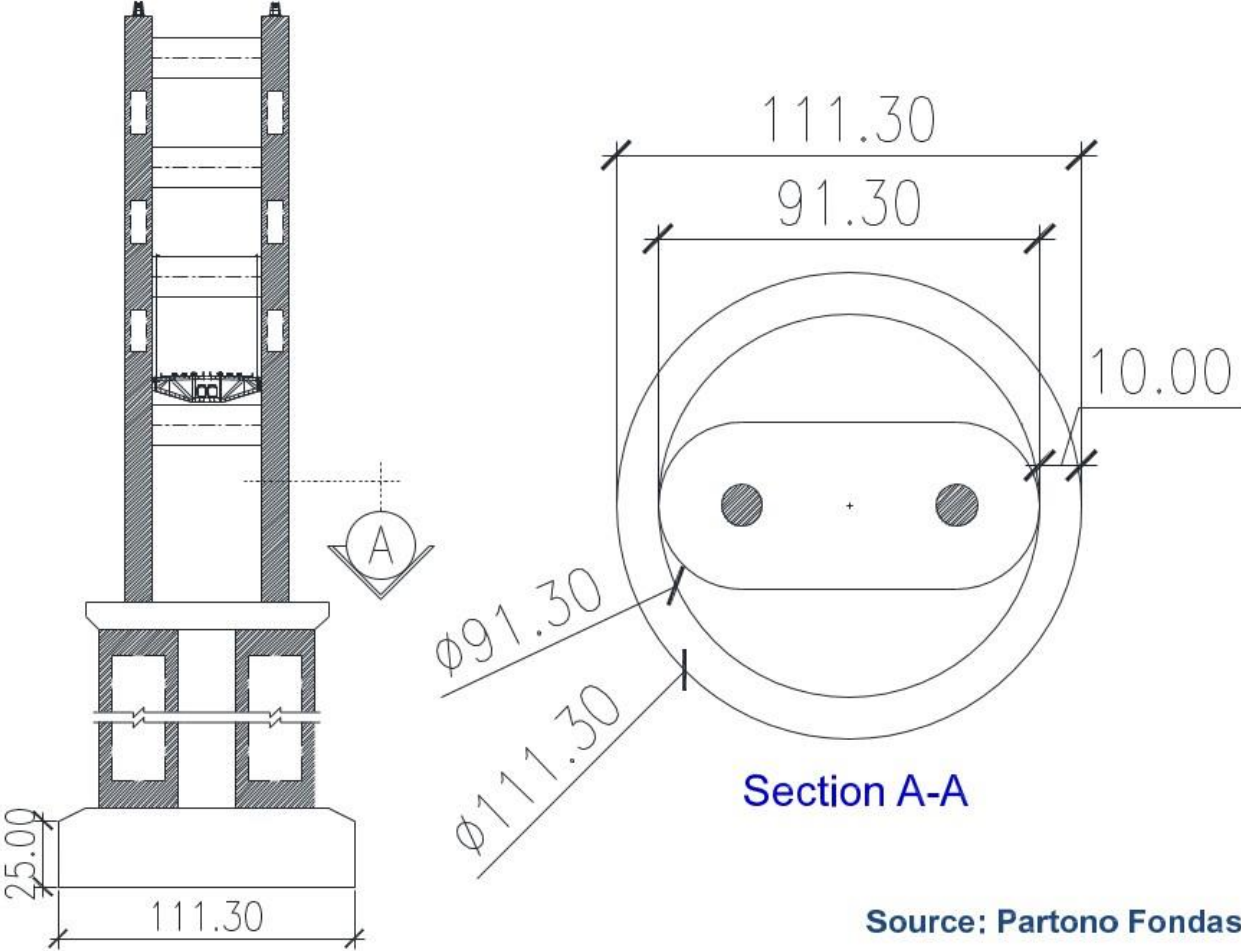
Due to the difficulty of crossing the deepest sea bed basin of Sunda Strait that reaches **130m** below sea level, on which the tower's foundation is limited to max **72m** water depth, it is proposed to use the large concrete caisson in form of hollow circle with outer diameter of **111.30m** and thickness of **30m** (25m at the edge), to be made by **60 MPa precast concrete** in a dry dock yard on shore, then to be poured and fulfilled later in place.

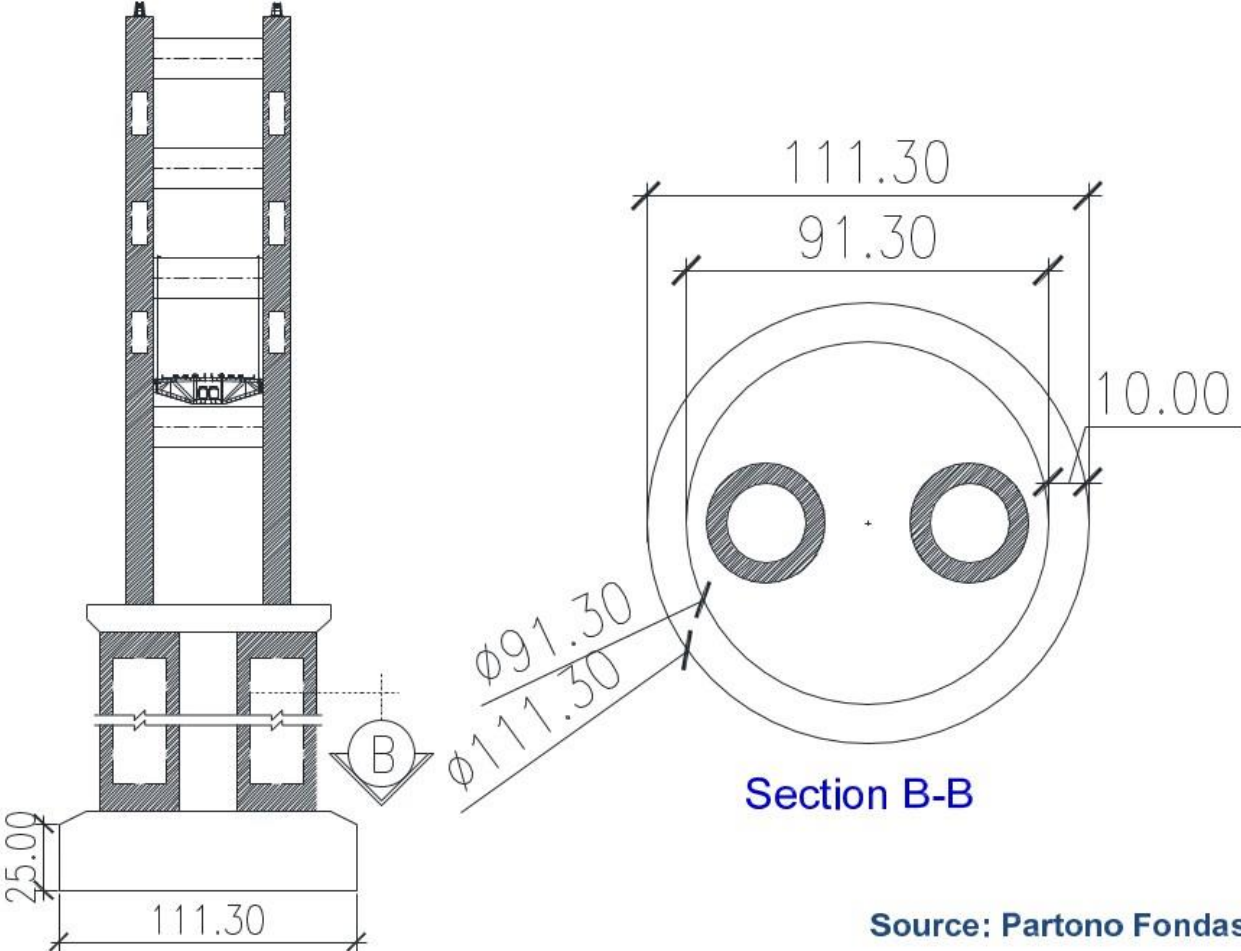
EAST BRIDGE LONG SECTION



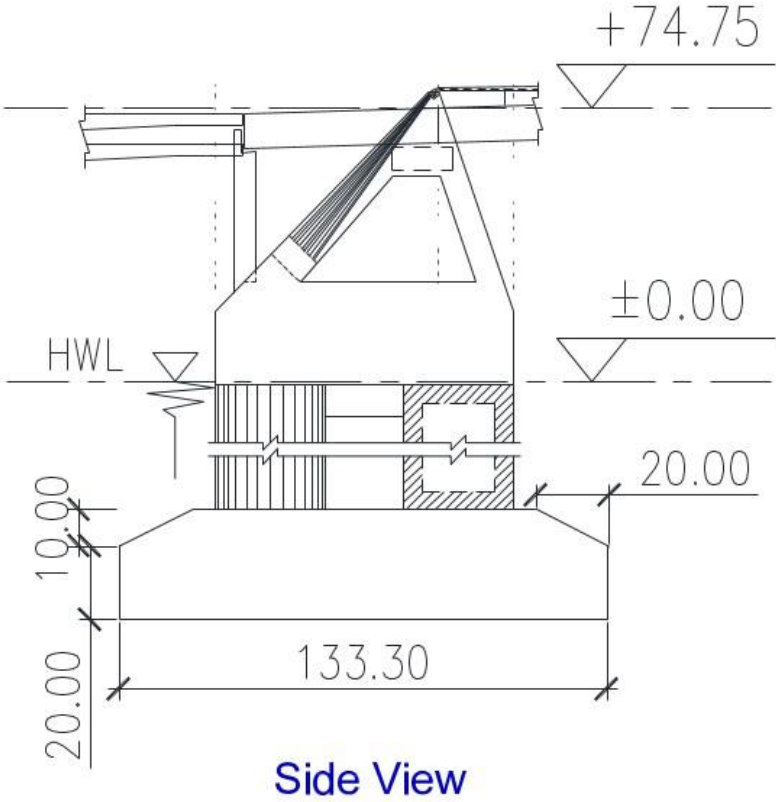
Source: Partono Fondas







Source: Partono Fondas

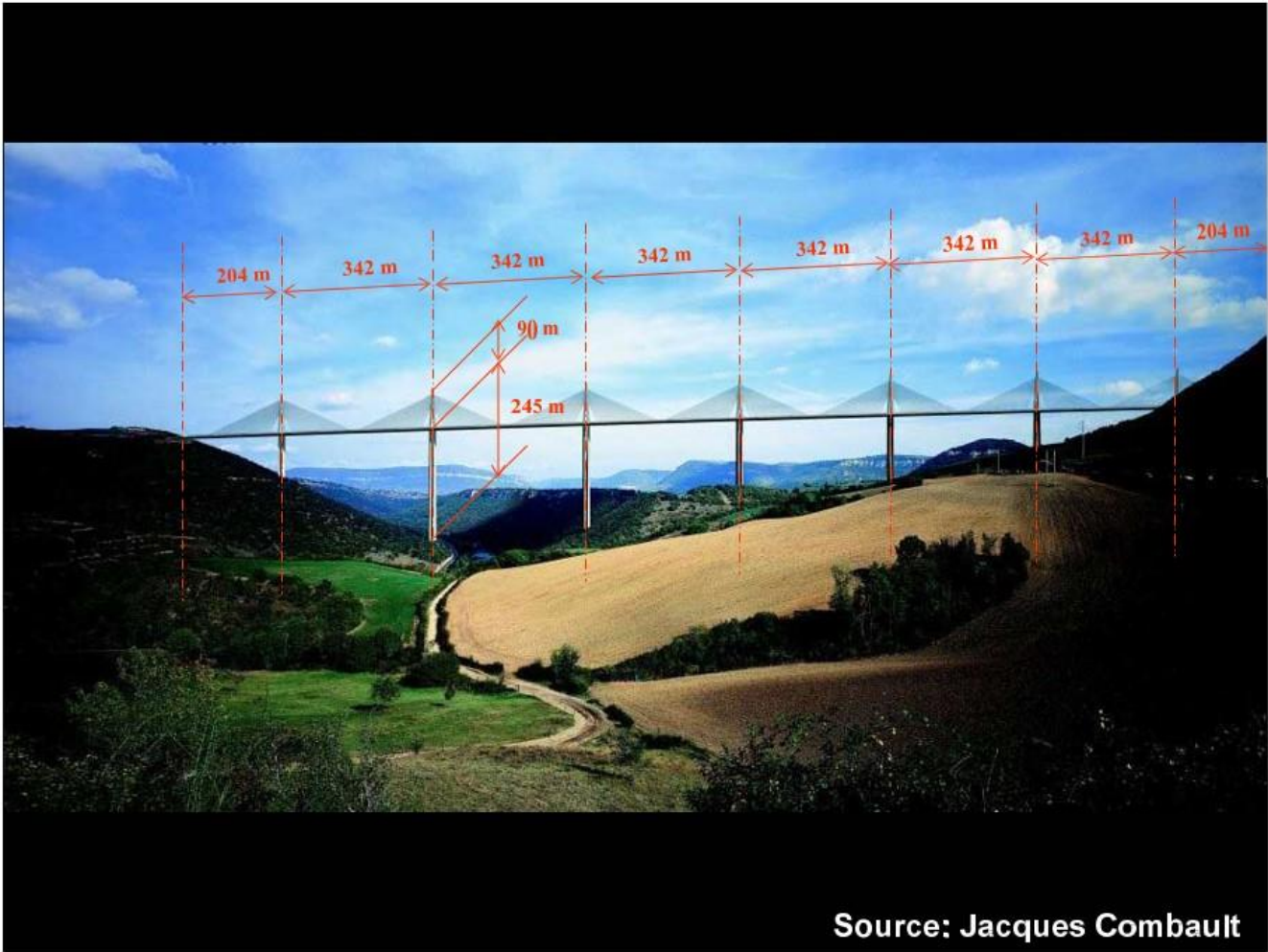


Source: Partono Fondas



Case Study 3

Millau Bridge



MILLAUBRIDGE (France)

Main Characteristics

Main Bridge :	7 Pylons – 8 Spans
Pylon Height:	292 feet (88.92 m) – Pier: 800 feet (244.00 m)
Main Span :	1122 feet (342.00 m)
Main Span Length-to- Pylon Height Ratio :	3.85
Deck Width :	92 feet (28.05 m – 32.05 m with Noses)
Girder Depth :	13.8 feet (4.20 m)
Span-to-Depth Ratio :	81.4
Cables :	Axial Fan Planes
Construction :	Steel - Incremental Launching

Source: Jacques Combault

MILLAU VIADUCT (France)



Source: Jacques Combault

MILLAU BRIDGE (France)

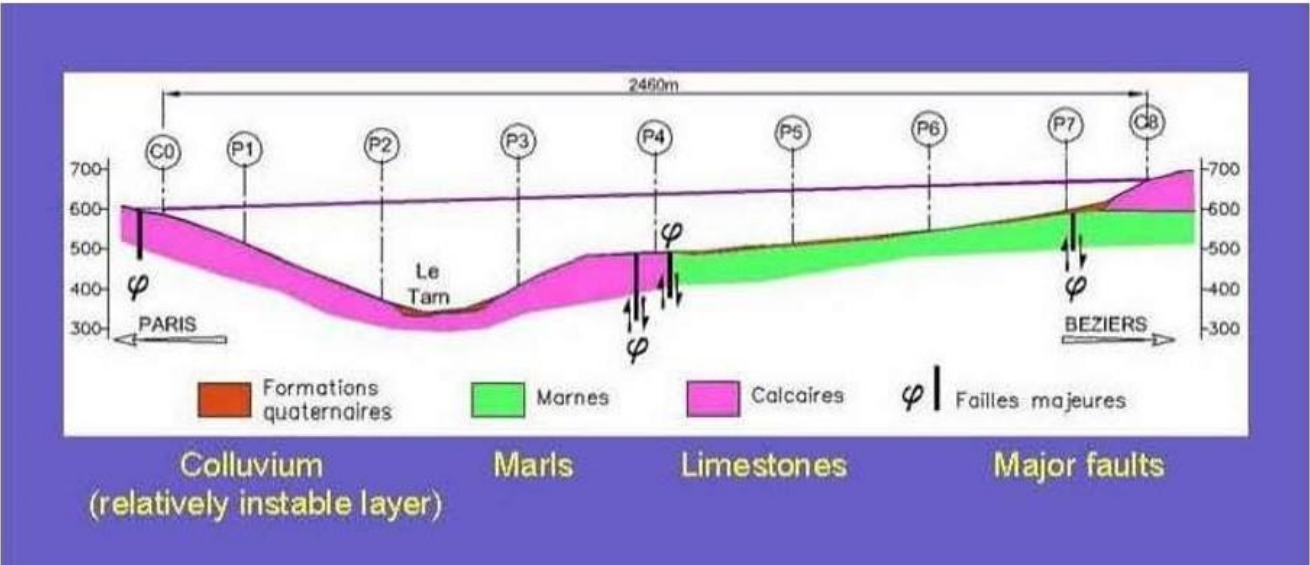


Source: Jacques Combault

CSB World Records

Source: Jacques Combault

Geotechnical Condition

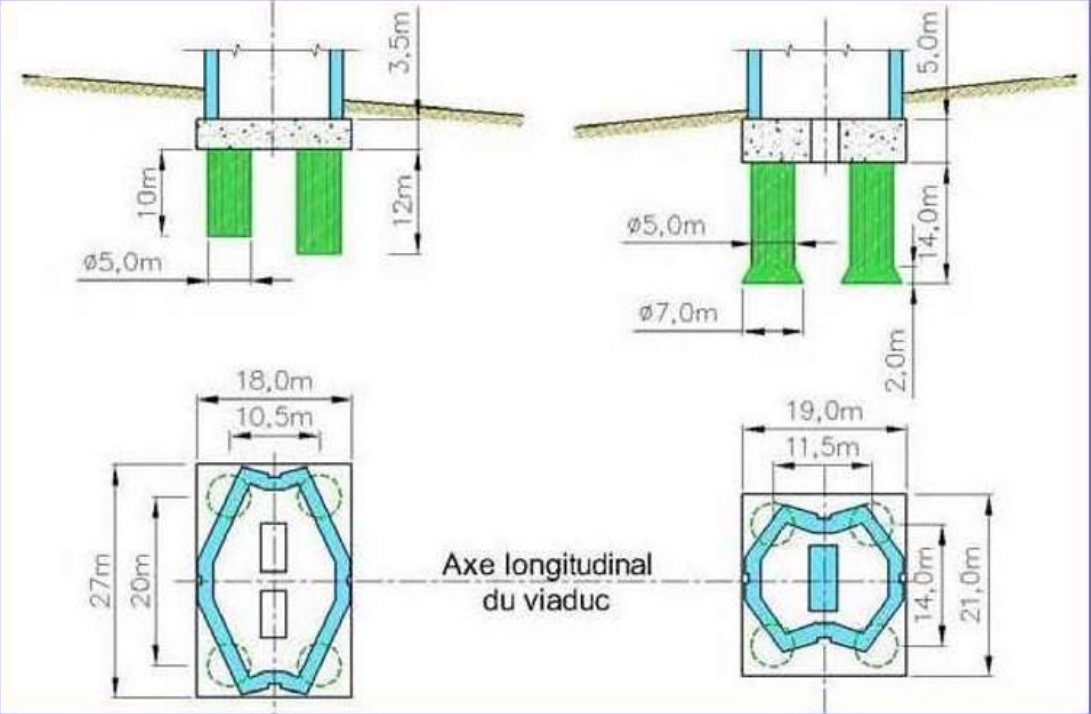


Source: Francois Schlosser

Foundations of the piers

Pier P2 (Limestone)

Pier P5 (Marl)

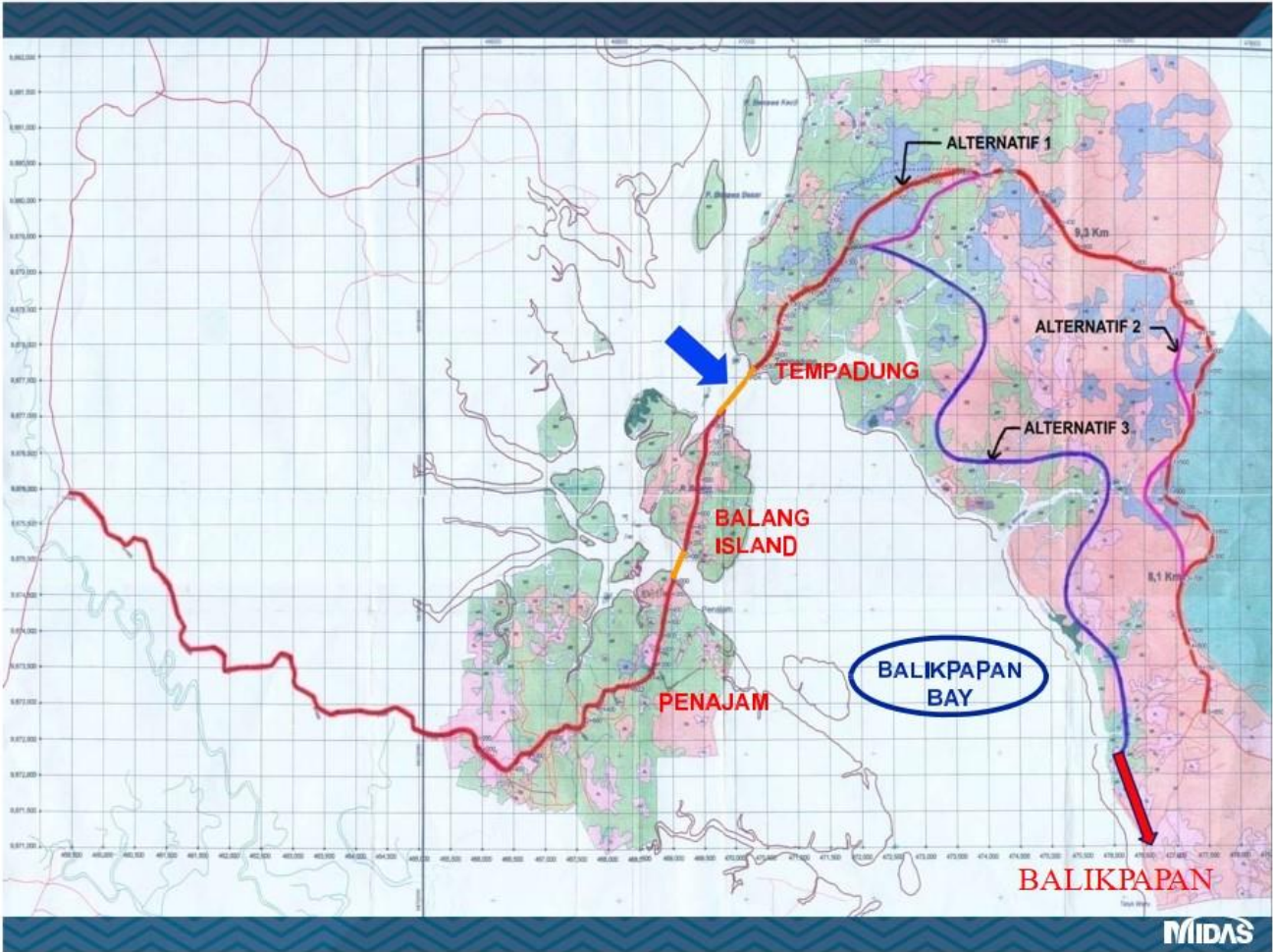


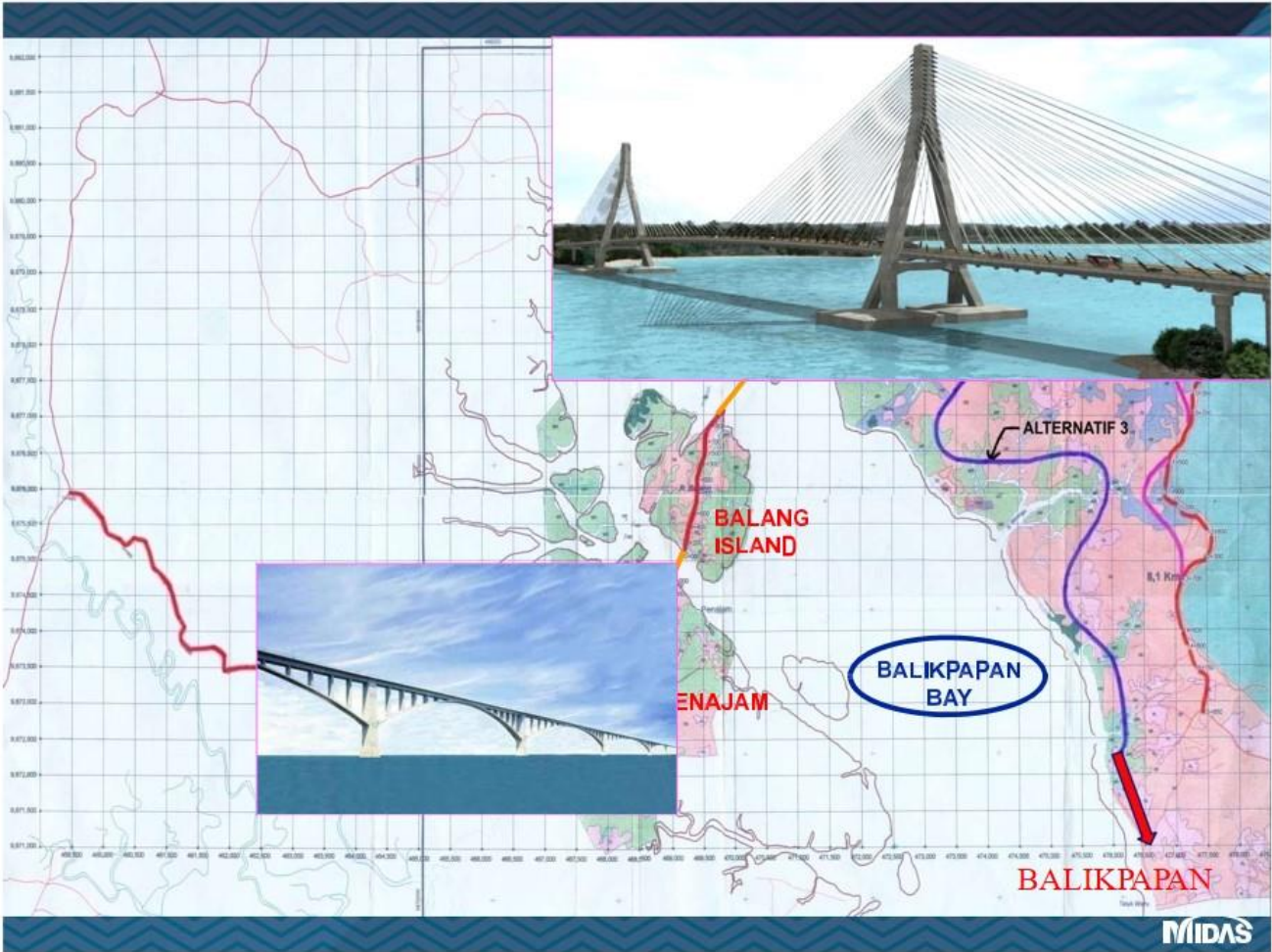
Source: Francois Schlosser



Case Study 4
Balang Island Bridge





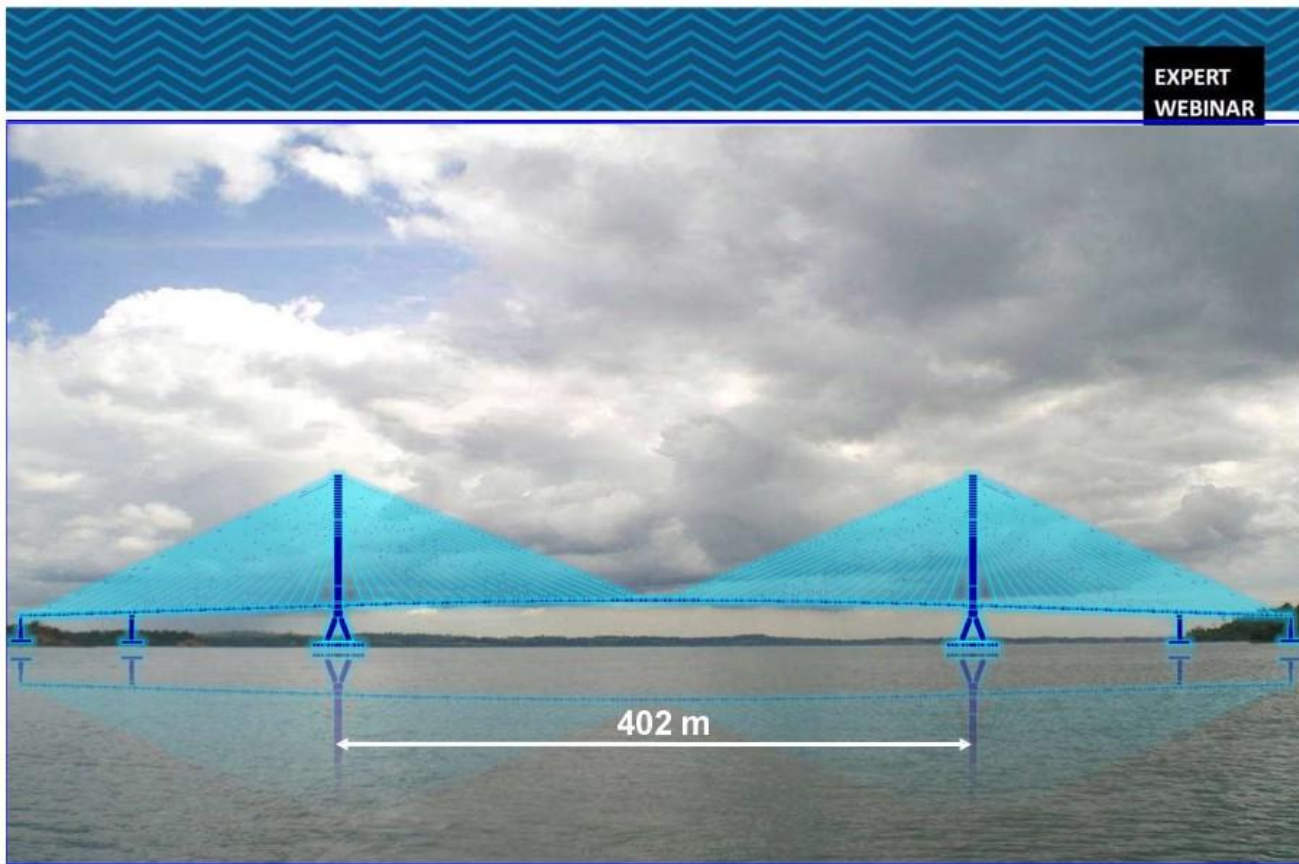


Balang Bridge (Short Span)



Source: Partono Fondas

MIDAS



Long-Span Balang Island Bridge



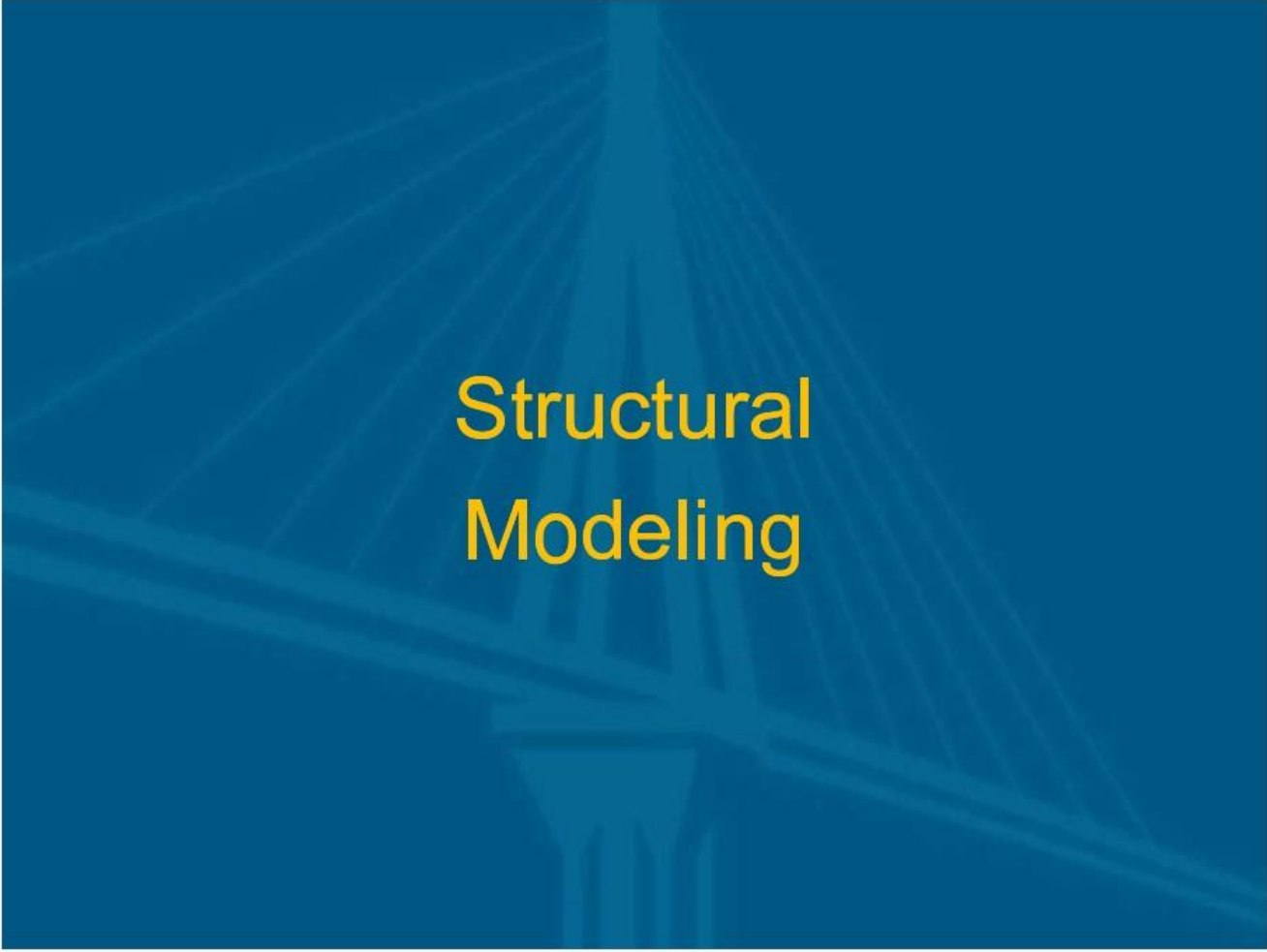
Balang Bridge (Long Span)



Source: Partono Fondas

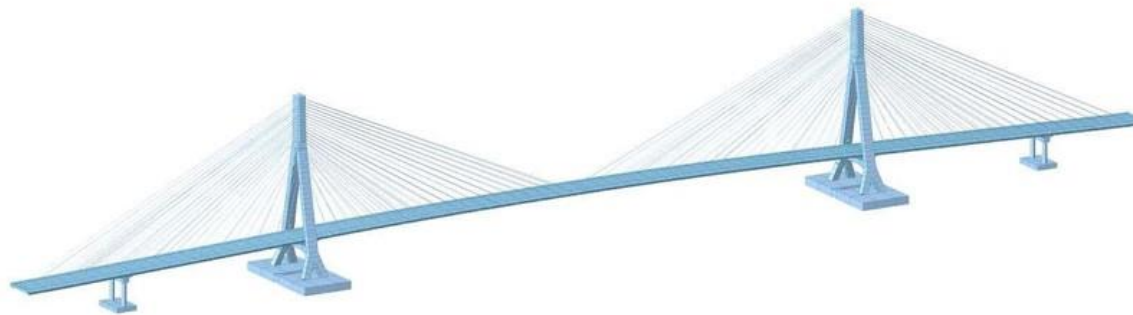
MIDAS



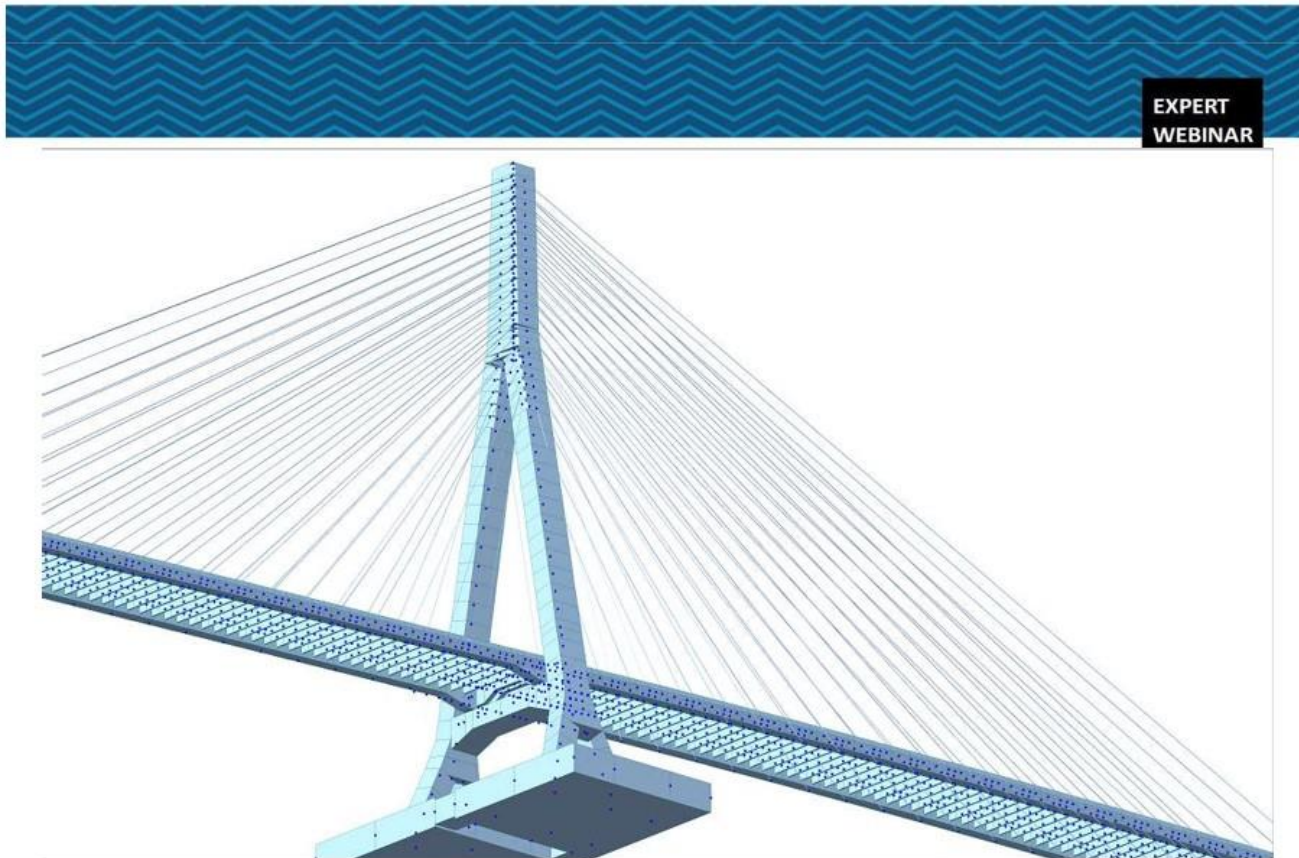


Structural Modeling

For a **long-span bridge** such as cable stayed bridge or suspension bridge, the structural modeling should be in **3-Dimension** so that the structural detailing can be well modeled.



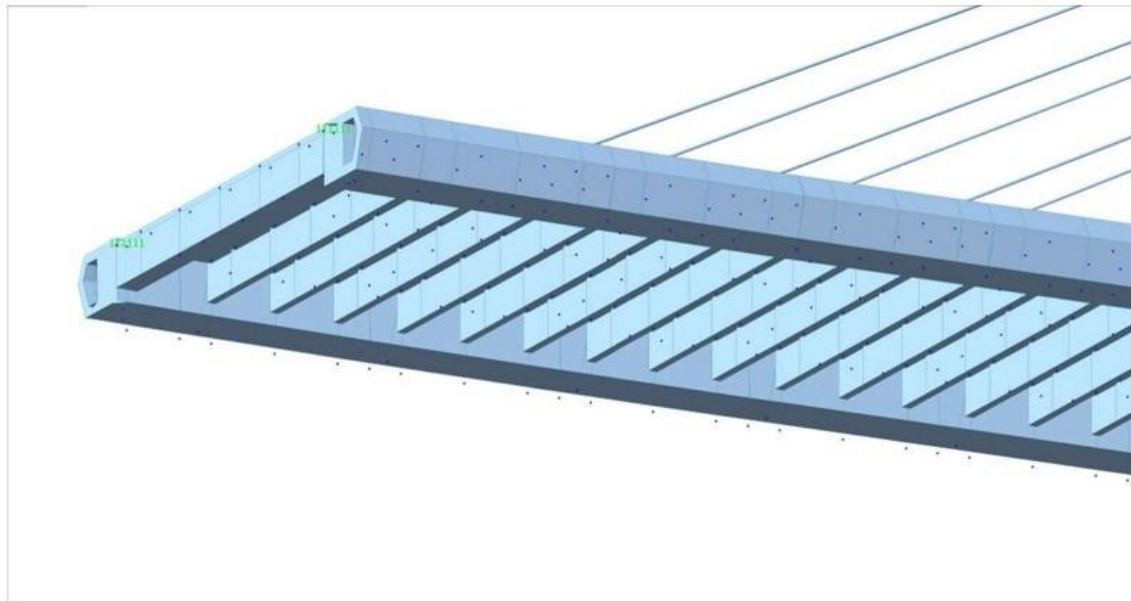
Source: Partono Fondas



EXPERT
WEBINAR

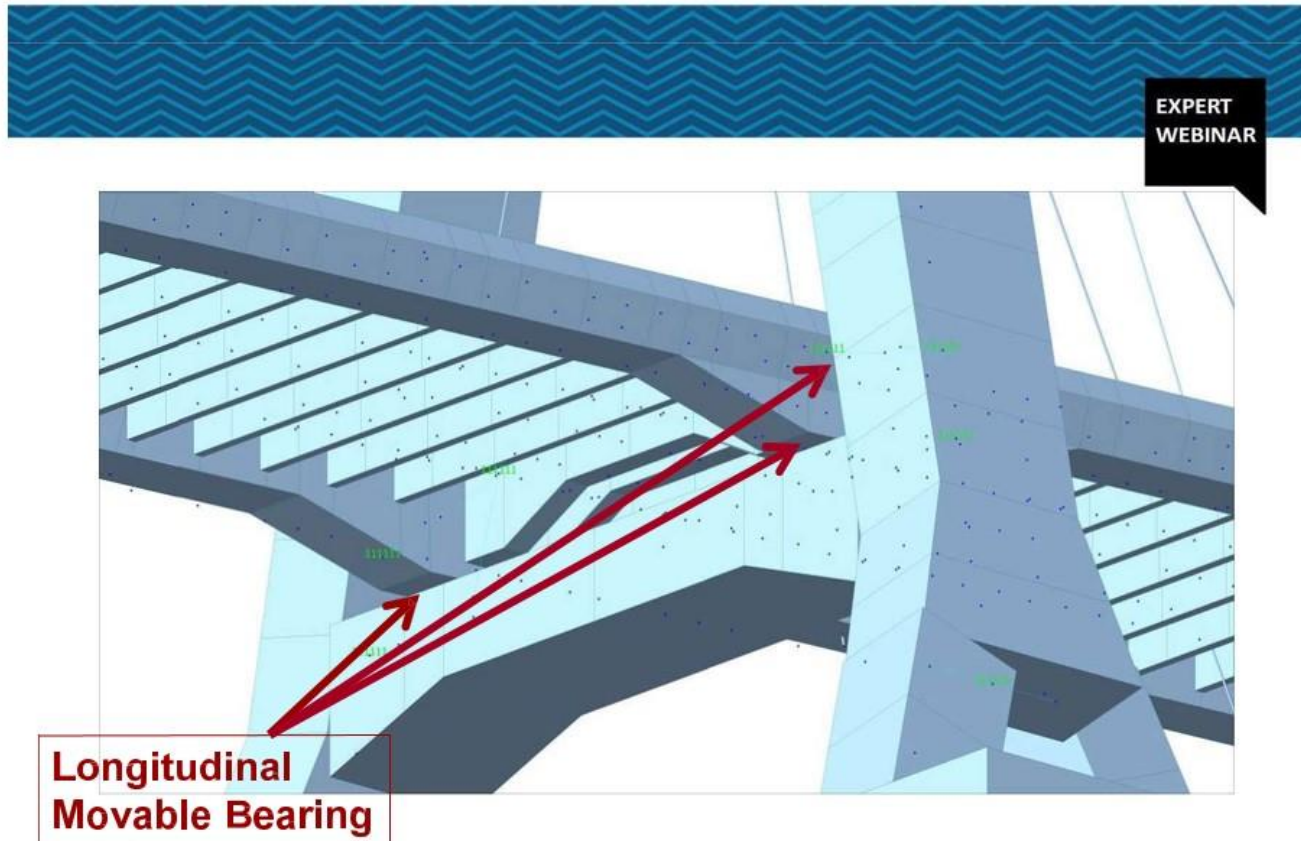
Source: Partono Fondas

MIDAS



Source: Partono Fondas



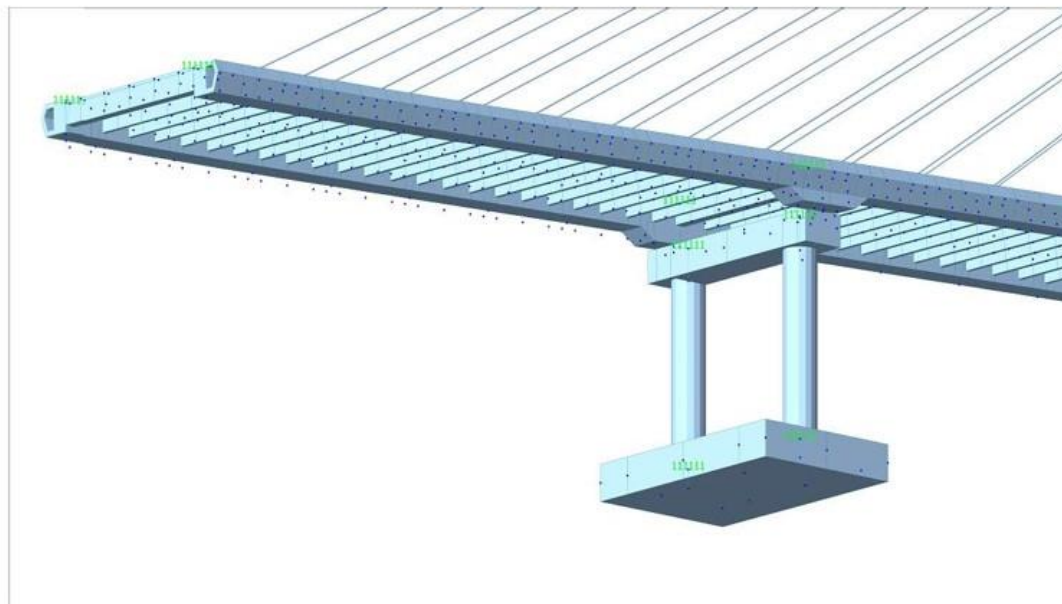


Source: Partono Fondas

MIDAS

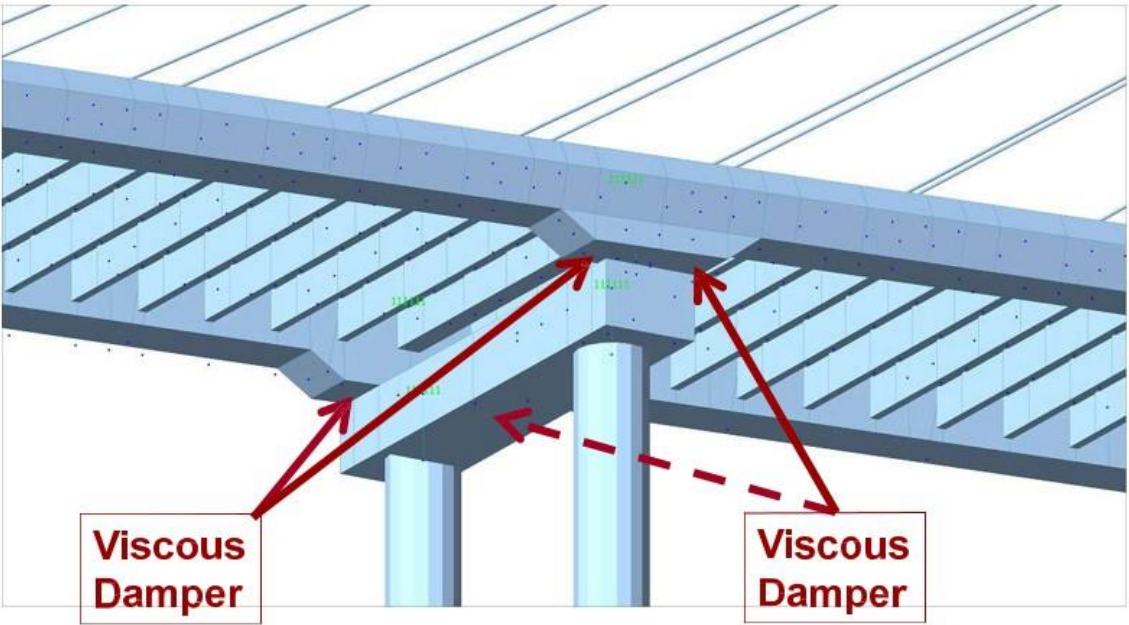


EXPERT
WEBINAR



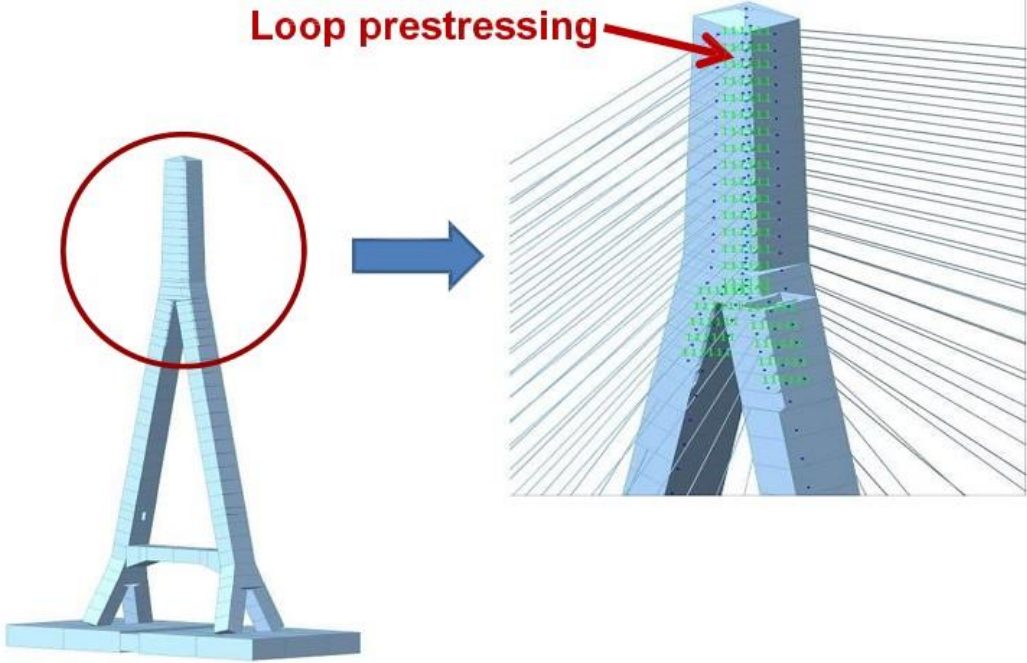
Source: Partono Fondas





Source: Partono Fondas



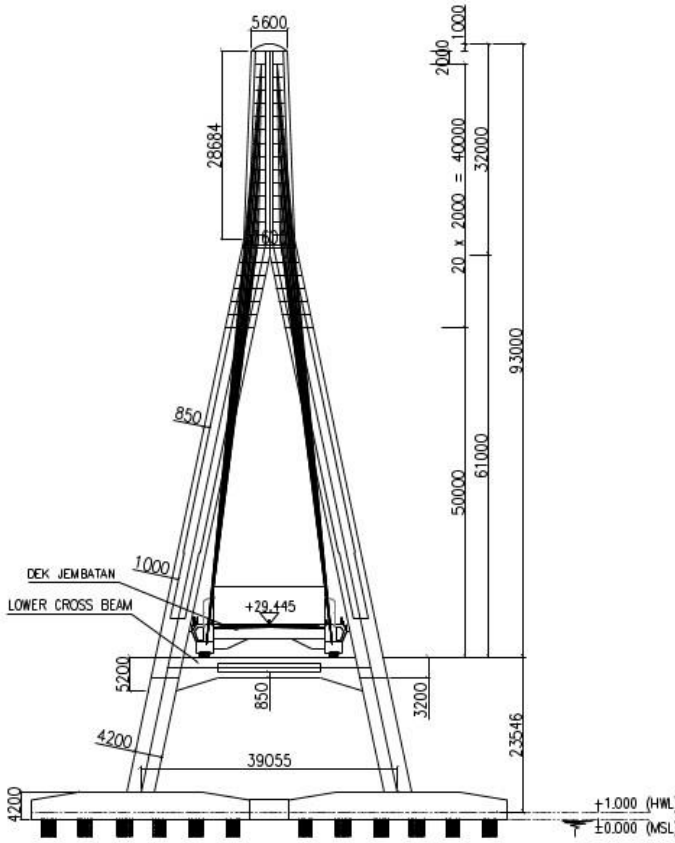


Source: Partono Fondas

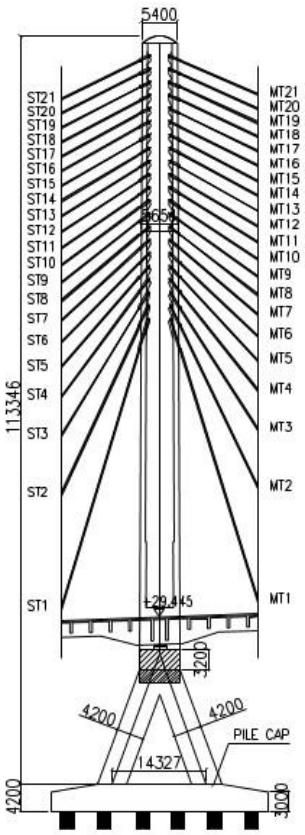




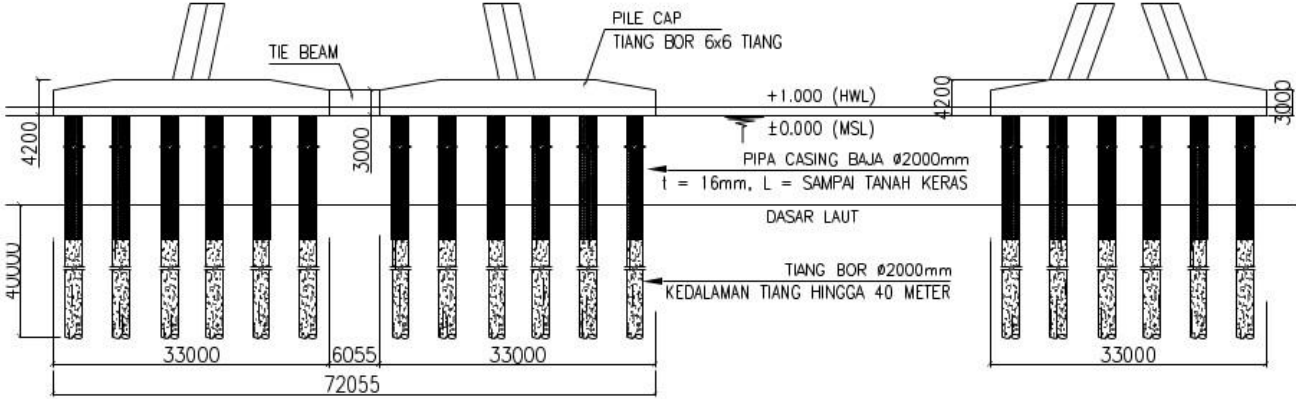
Bridge Foundation



Pylon

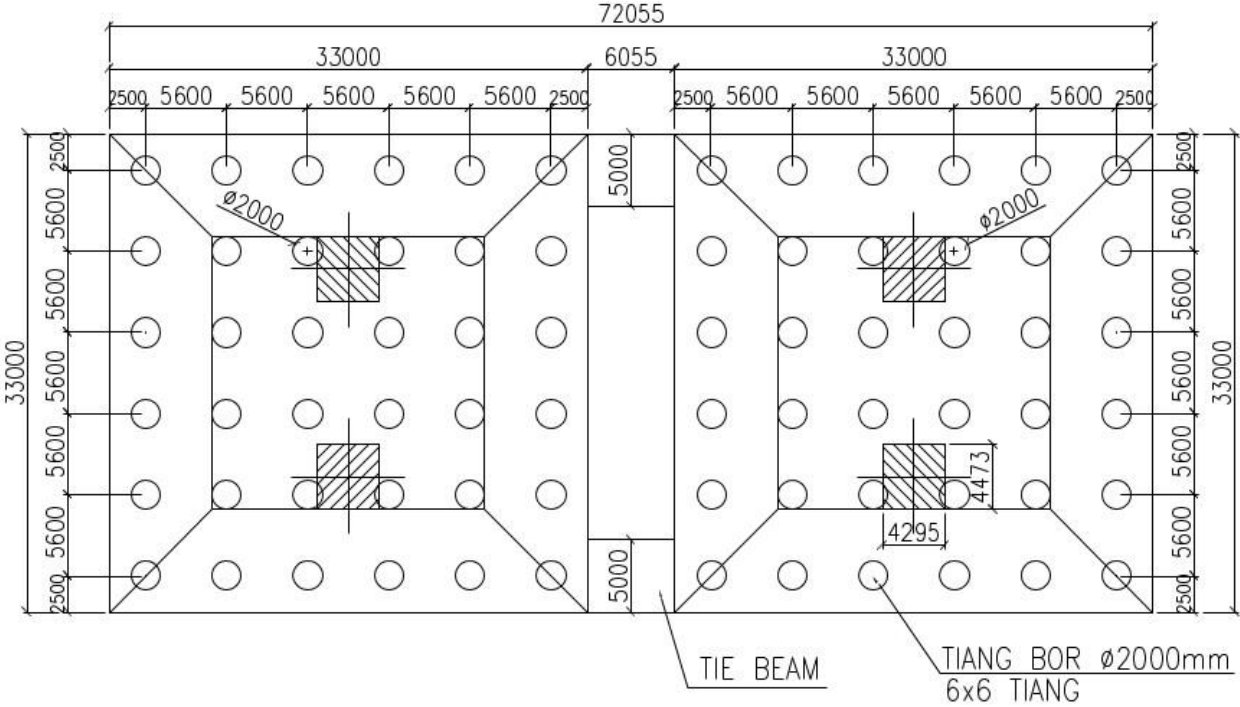


Source: Partono Fondas



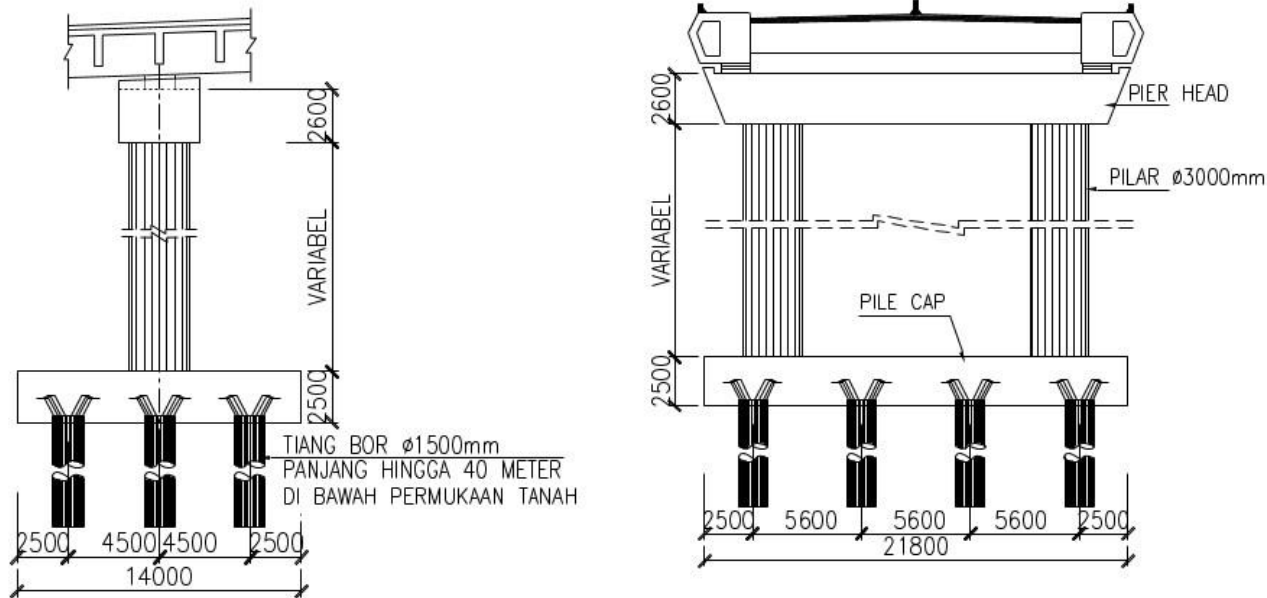
Tampak Samping Tiang Bor Untuk Pylon

Source: Partono Fondas



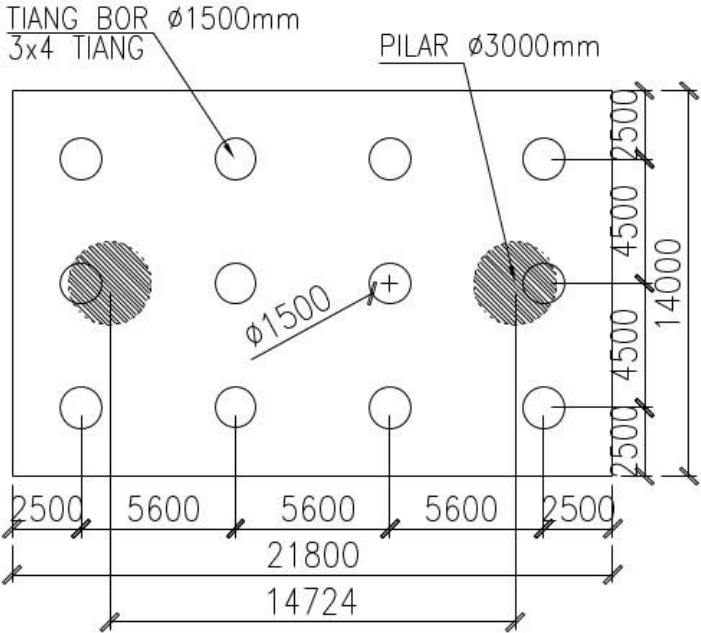
Denah Tiang Bor Pylon

Source: Partono Fondas



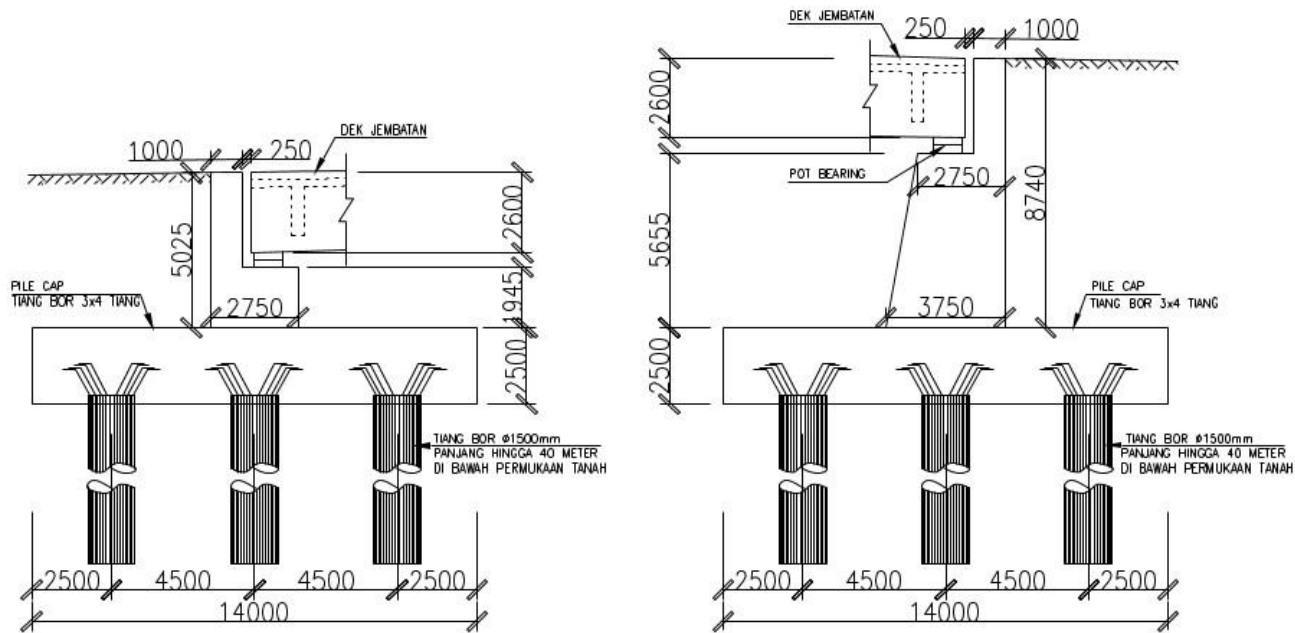
Tampak Tiang Bor Untuk Pilar

Source: Partono Fondas



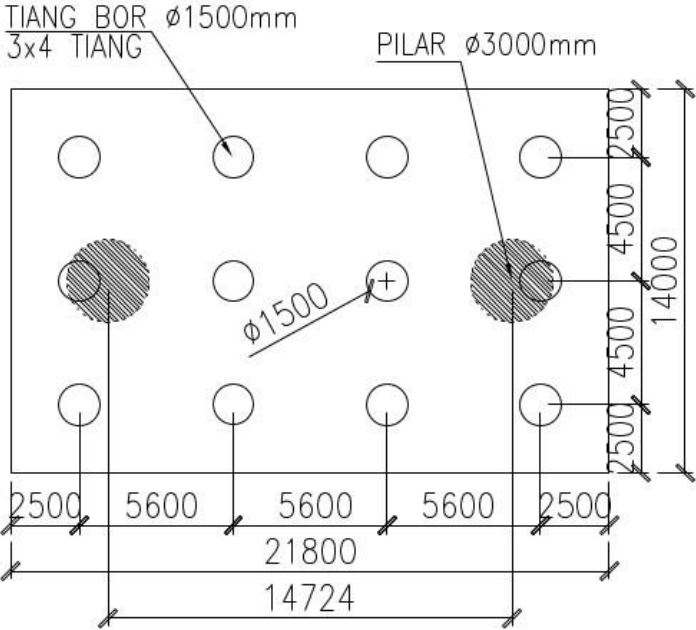
Denah Tiang Bor Untuk Pilar

Source: Partono Fondas



Tampak Samping Tiang Bor Untuk Abutmen

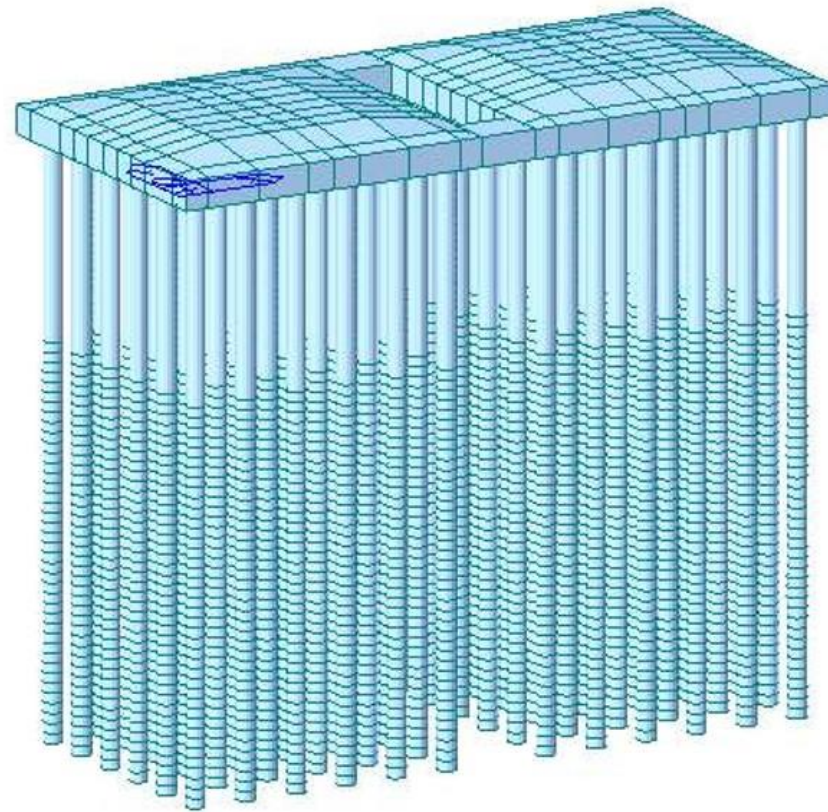
Source: Partono Fondas



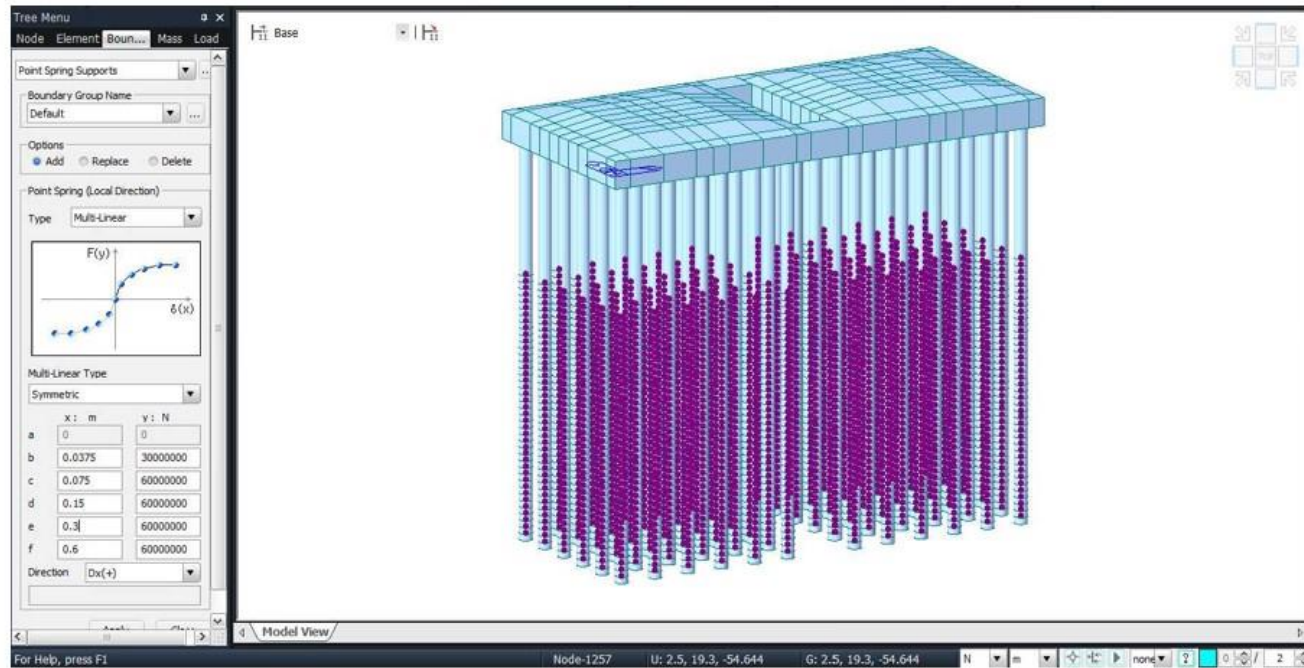
Denah Tiang Bor Untuk Abutmen

Source: Partono Fondas

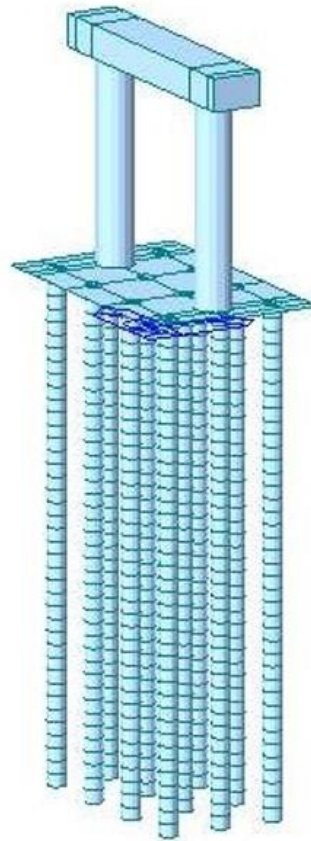
Foundation Modeling



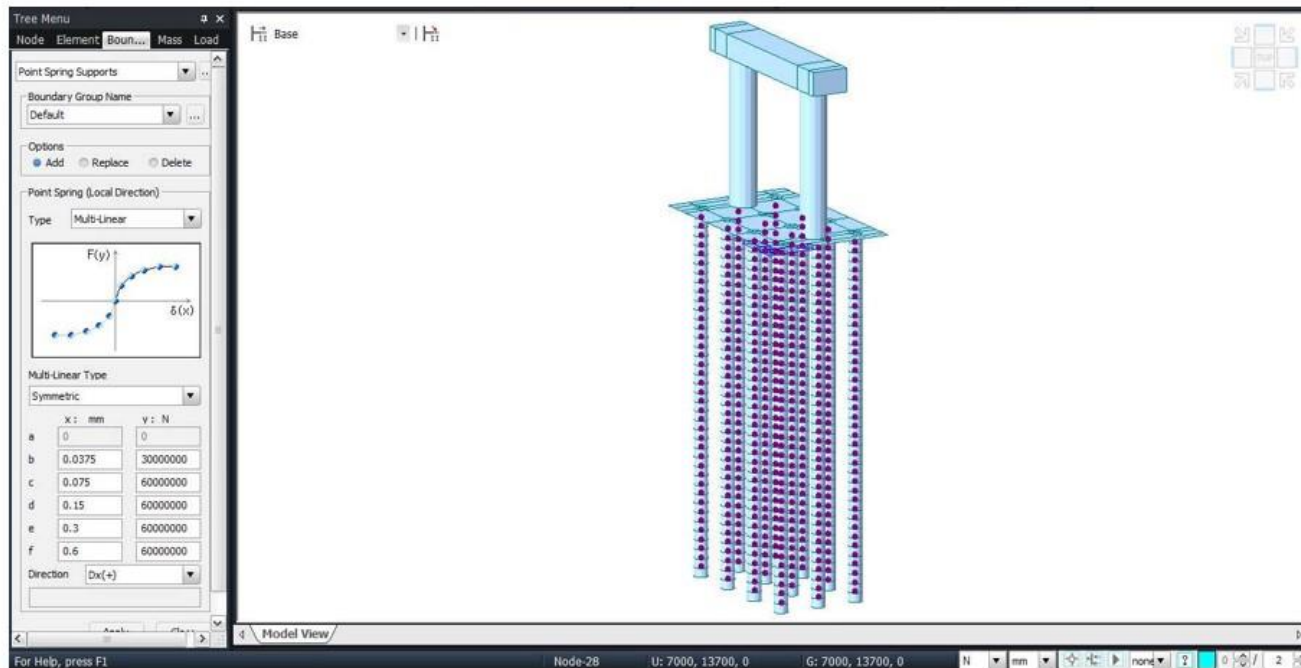
Pemodelan 3D Struktur Pile Cap Untuk Pylon



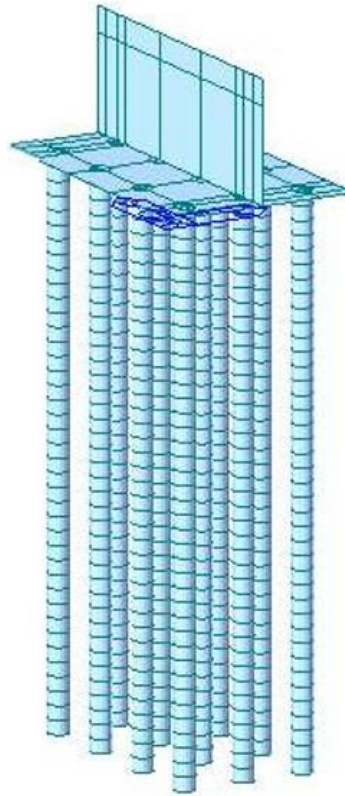
Pemodelan Pegas Multi Linear Pondasi Pylon



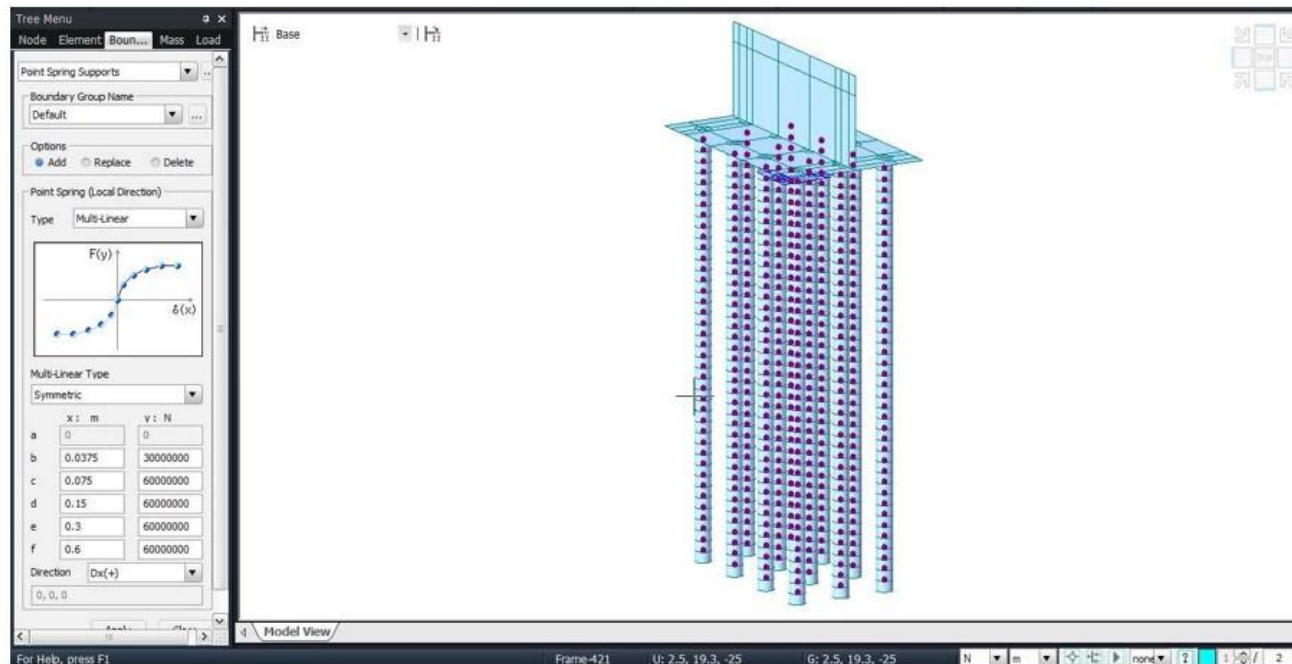
Pemodelan 3D Struktur Pile Cap Untuk Pilar



Pemodelan Pegas Multi Linear Pondasi Pilar

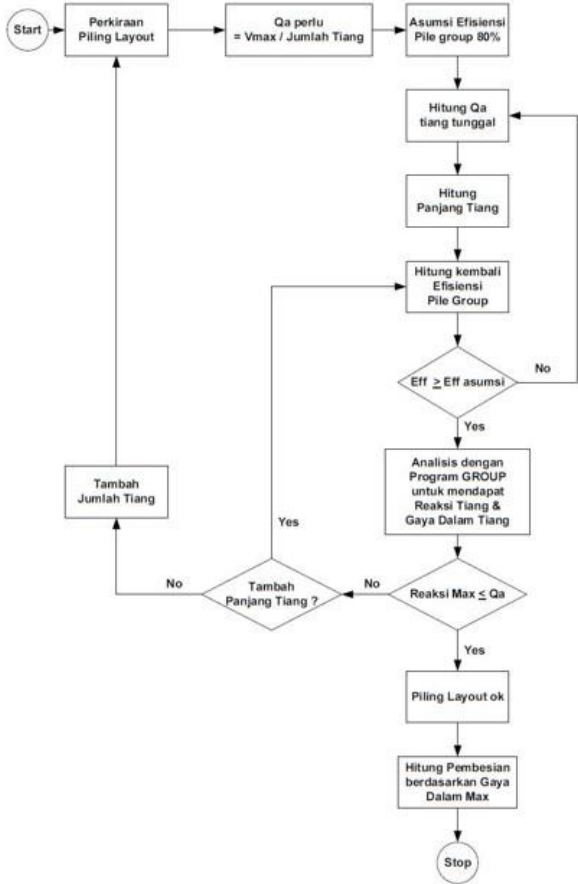


Pemodelan 3D Struktur Pile Cap Untuk Abutmen

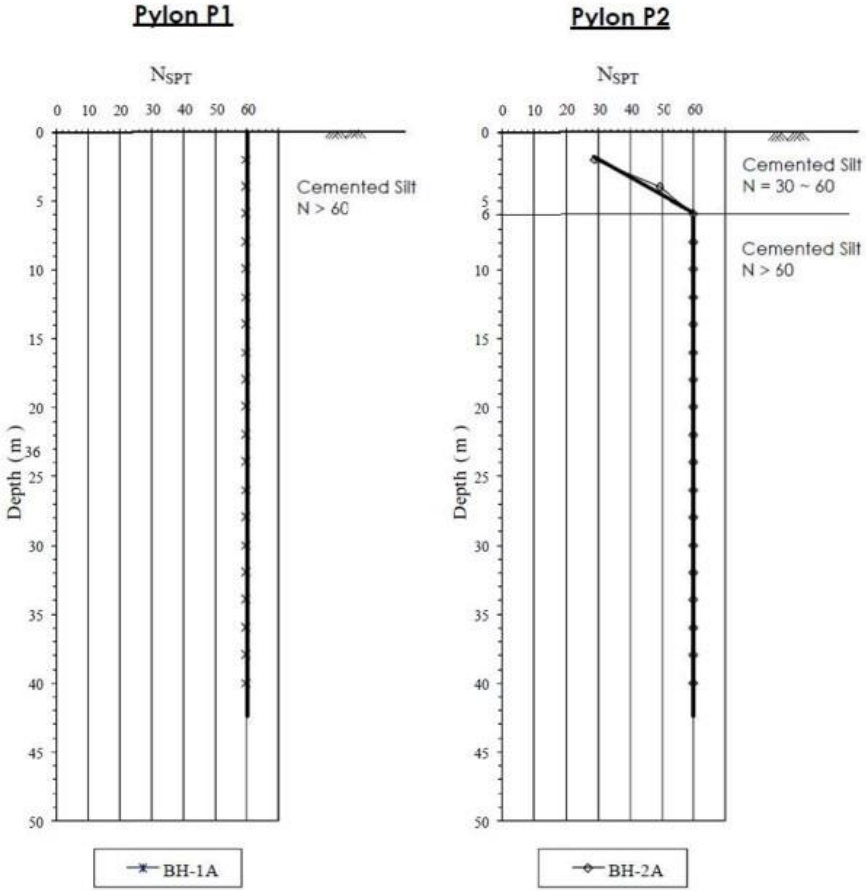


Pemodelan Pegas Multi Linear Pondasi Abutmen

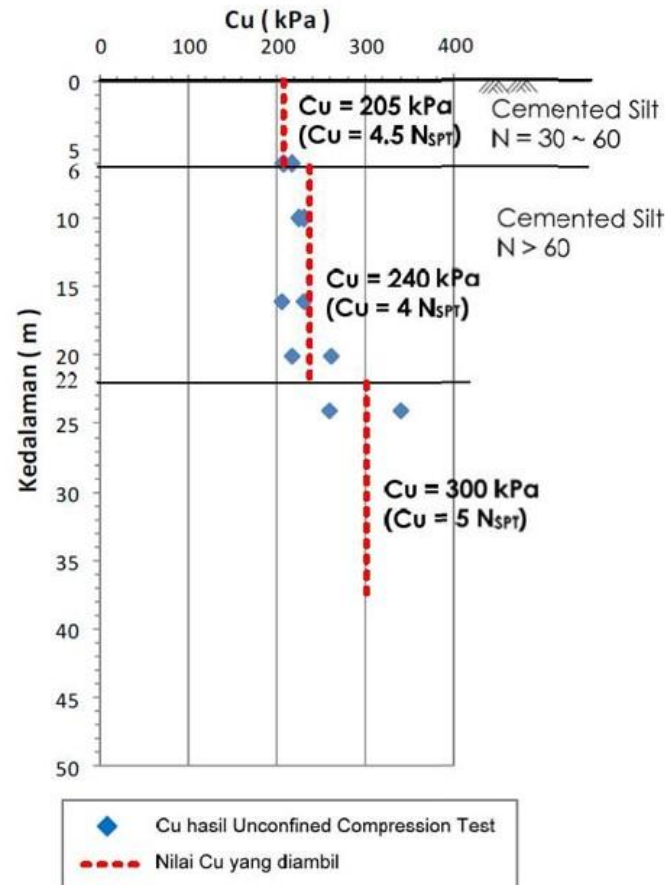
Bearing Capacity Analysis



Bagan Alir Analisis Pondasi



Profil Tanah dan N-SPT Pada Posisi Struktur Pylon



Hasil Undrained Shear Strength (C_u) pada Pylon P2

Tabel Kombinasi reaksi dasar kaki pylon pada beban maksimum arah longitudinal jembatan (Arah X)

Kombinasi	Nodal	FX (tonf)	FY (tonf)	FZ (tonf)	MX (tonf*m)	MY (tonf*m)	MZ (ton*m)
SLS17	3373	-2816.95	1772.28	8649.36	701.44	199.12	40.54
SLS17	3375	3288.44	2223.93	9463.99	793.79	-3424.67	167.91
SLS17	3377	-2810.18	-1771.80	9486.53	-698.85	187.32	581.42
SLS17	3379	3295.20	-2224.37	10302.99	-796.80	-3436.51	-790.19

Tabel Kombinasi reaksi dasar kaki pylon pada beban maksimum arah lateral jembatan (Arah Y)

Kombinasi	Nodal	FX (tonf)	FY (tonf)	FZ (tonf)	MX (tonf*m)	MY (tonf*m)	MZ (ton*m)
SLS16	3373	-3238.72	2282.68	10708.00	993.34	4405.32	-1040.26
SLS16	3375	2831.17	1691.26	8975.30	493.73	797.71	300.50
SLS16	3377	-3245.44	-2283.12	9871.15	-996.31	4417.09	419.53
SLS16	3379	2824.45	-1690.78	8136.61	-491.14	809.48	320.55

Tabel Kombinasi reaksi dasar kaki pylon pada beban maksimum arah vertikal jembatan (Arah Z)

Kombinasi	Nodal	FX (tonf)	FY (tonf)	FZ (tonf)	MX (tonf*m)	MY (tonf*m)	MZ (ton*m)
SLS15	3373	-2869.53	1989.91	9871.00	1013.68	2017.78	-433.04
SLS15	3375	3200.40	1984.45	8136.45	472.71	-1588.25	-307.03
SLS15	3377	-2862.76	-1989.43	10708.17	-1011.11	2005.98	1055.00
SLS15	3379	3207.16	-1984.89	8975.45	-475.71	-1600.09	-315.24

Data Beban Pada Kondisi Service

Tabel Kombinasi reaksi dasar kaki pylon pada beban maksimum arah longitudinal jembatan (Arah X)

Kombinasi	Nodal	FX (tonf)	FY (tonf)	FZ (tonf)	MX (tonf*m)	MY (tonf*m)	MZ (ton*m)
U5	3373	-3829.85	2354.49	11358.89	784.04	-173.71	155.91
U5	3375	4463.67	3078.35	13334.26	1121.49	-5052.15	443.74
U5	3377	-3821.73	-2353.92	12363.49	-780.95	-187.87	590.43
U5	3379	4471.78	-3078.88	14341.06	-1125.13	-5066.36	-1190.47

Tabel Kombinasi reaksi dasar kaki pylon pada beban maksimum arah lateral jembatan (Arah Y)

Kombinasi	Nodal	FX (tonf)	FY (tonf)	FZ (tonf)	MX (tonf*m)	MY (tonf*m)	MZ (ton*m)
U4	3373	-4408.10	3265.44	15504.65	1562.54	7367.88	-1790.52
U4	3375	3794.22	2110.71	10927.22	321.09	2533.23	-48.48
U4	3377	-4416.16	-3265.96	14500.43	-1566.14	7382.00	1045.64
U4	3379	3786.16	-2110.13	9920.79	-317.99	2547.35	793.76

Tabel Kombinasi reaksi dasar kaki pylon pada beban maksimum arah vertikal jembatan (Arah Z)

Kombinasi	Nodal	FX (tonf)	FY (tonf)	FZ (tonf)	MX (tonf*m)	MY (tonf*m)	MZ (ton*m)
U3	3373	-3965.07	2914.11	14500.25	1586.95	4502.83	-1061.86
U3	3375	4237.30	2462.54	9920.60	295.87	-329.93	-777.52
U3	3377	-3956.94	-2913.54	15504.85	-1583.90	4488.67	1808.21
U3	3379	4245.41	-2463.06	10927.40	-299.47	-344.13	30.83

Data Beban Pada Kondisi Ultimit

Perhitungan daya dukung tekan bore pile

$$Q_{\text{all}} = \frac{Q_s}{SF}$$

Dimana:

Q_{all} = Daya dukung izin untuk beban tekan

SF = Faktor keamanan = 3

Q_s = Daya dukung Friksi
= $A_s \times f_s$

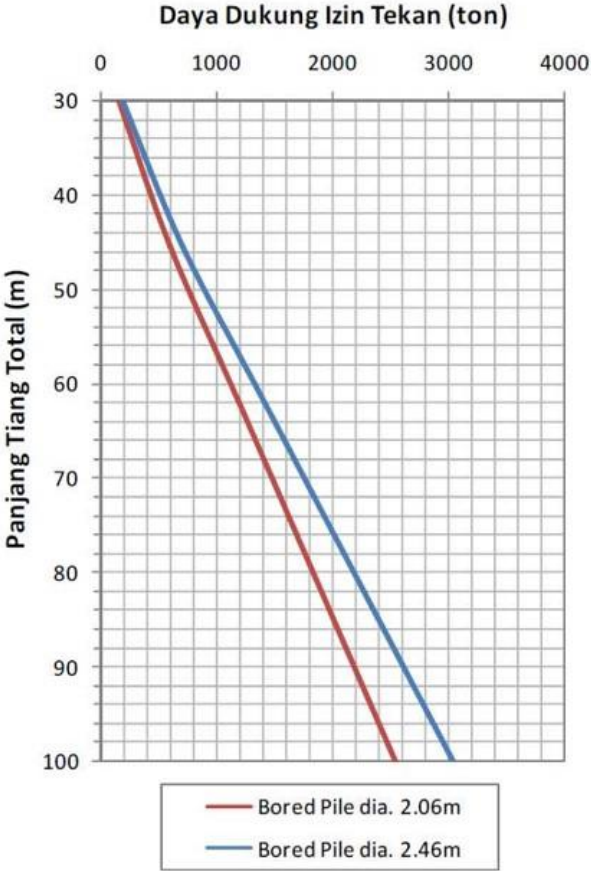
A_s = Luas selimut tiang

f_s = Unit Friksi

Cohesive soils $\rightarrow f_s = \alpha C_u$

$\alpha = 0.55$ (referensi : Skempton)

Sandy soils $\rightarrow f_s = 0.2 N_{\text{SPT}} \text{ (t/m}^2\text{)}$



Grafik Daya Dukung Izin Tekan Terhadap Kedalaman Tiang

Perhitungan daya dukung tarik bore pile

$$Q_{\text{all}(\text{tarik})} = \frac{Q_s(\text{tarik}) + W_p}{S.F}$$

Dimana:

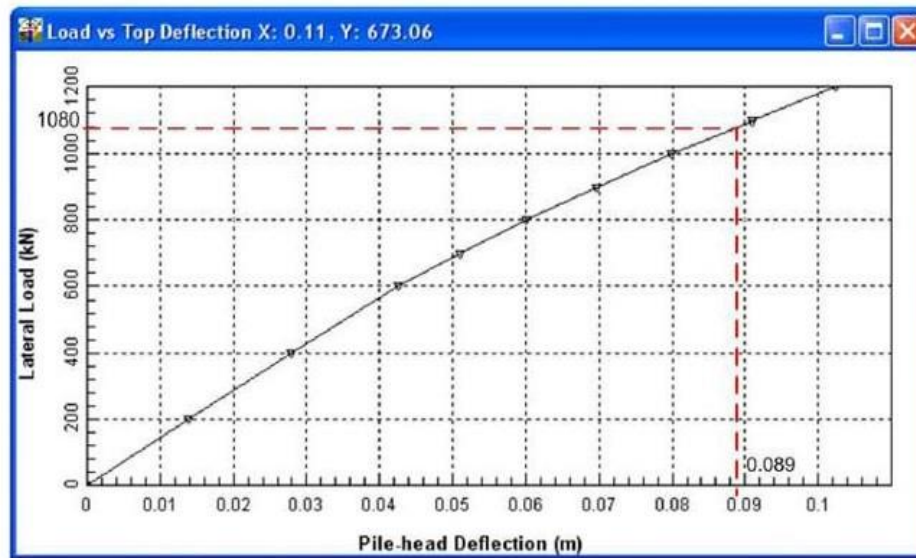
$Q_s(\text{tarik})$ = daya dukung friksi untuk beban tarik

= 0.7 x Q_s tekan untuk tanah sand

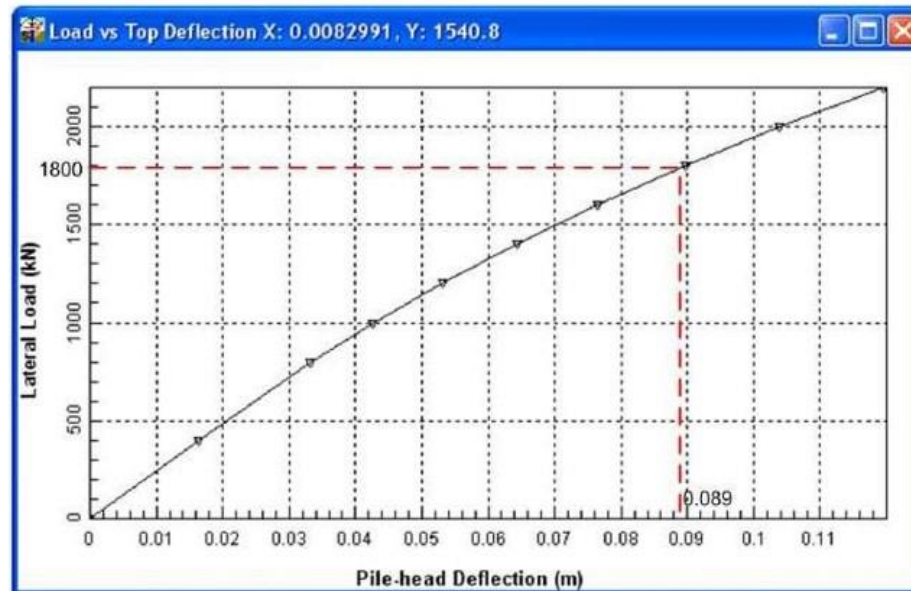
= 0.9 x Q_s tekan untuk tanah clay

S.F. = faktor keamanan = 3

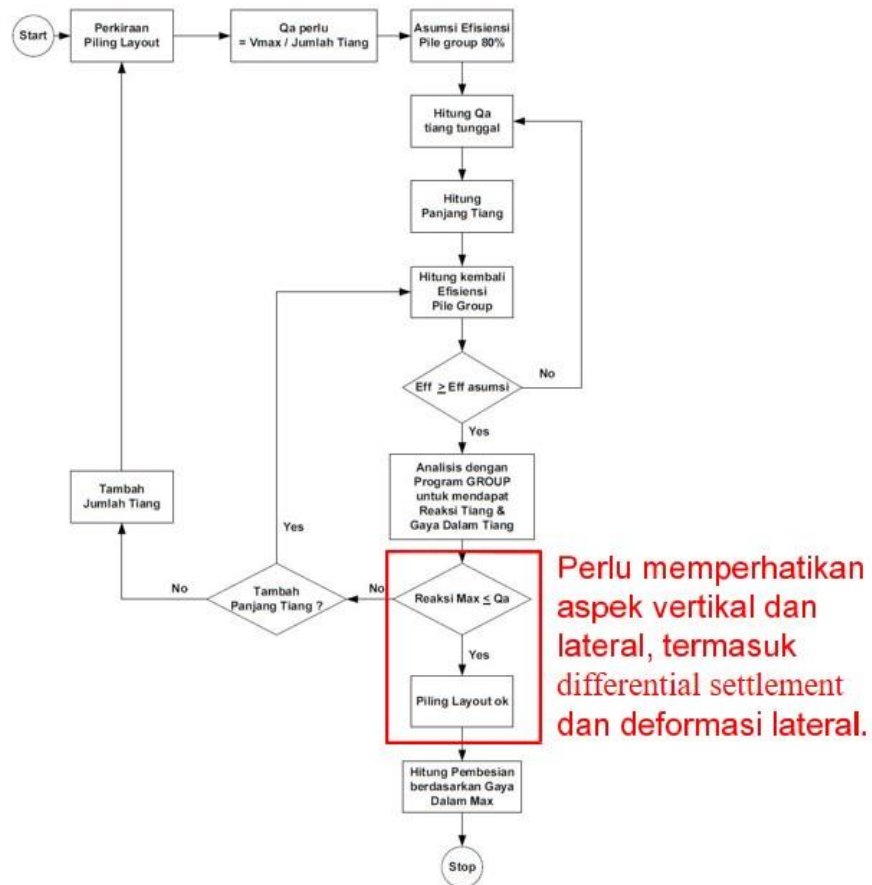
W_p = berat sendiri tiang



Grafik Beban Terhadap Defleksi (dia. 2.1m/2.06m)



Grafik Beban Terhadap Defleksi (dia. 2.5m/2.46m)



Analisis Keamanan Pondasi

KESIMPULAN

Pondasi adalah komponen yang sangat penting dari keseluruhan struktur jembatan, sehingga konsep penetapan **tipe** dan **konfigurasi** pondasi merupakan bagian yang penting di dalam desain jembatan.

Pelaksanaan pondasi seringkali merupakan bagian yang “**krusial**” atau “**kritis**” dalam keseluruhan proses pelaksanaan jembatan, sehingga perlu direncanakan dengan matang, baik dari segi **keamanan** dan **stabilitas struktur pondasi**, maupun juga **fisibiliti pelaksanaannya** di lokasi jembatan.