What prompted the collapse of the Chirajara Bridge ?

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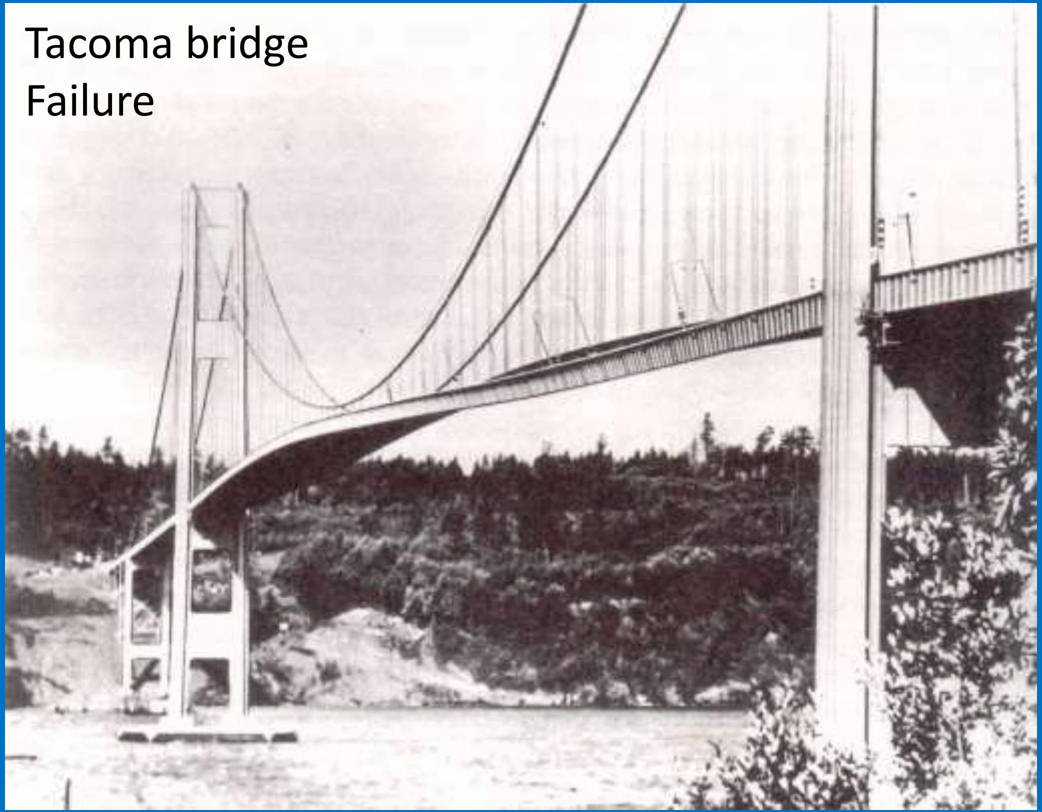
Cable stayed bridges are very efficient and stable bridges

The collapse of a cable stayed bridge is not usual

Whenever failures of suspended bridges have occurred they happened on the roadway or the cables.



Failure of the tower of cable suspended bridges is something unprecedented.

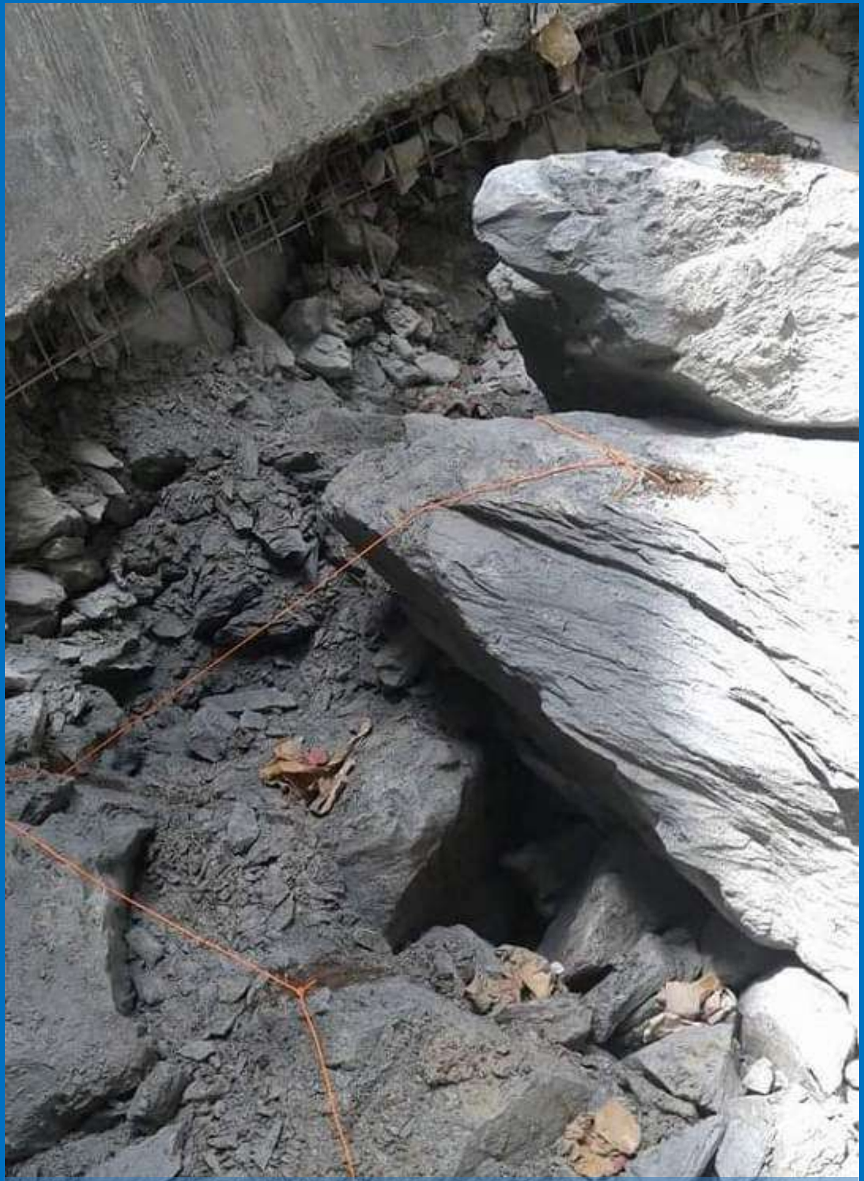
Why the pylon (tower) failed at Chirajara?

Let us analize the geology, the foundation and the shape of the tower.

It was an engineering challenge to effectively support the bridge towers on <u>highly sloped hillsides and geologically complex stratum.</u>

Geology in the Chirajara Bridge zone

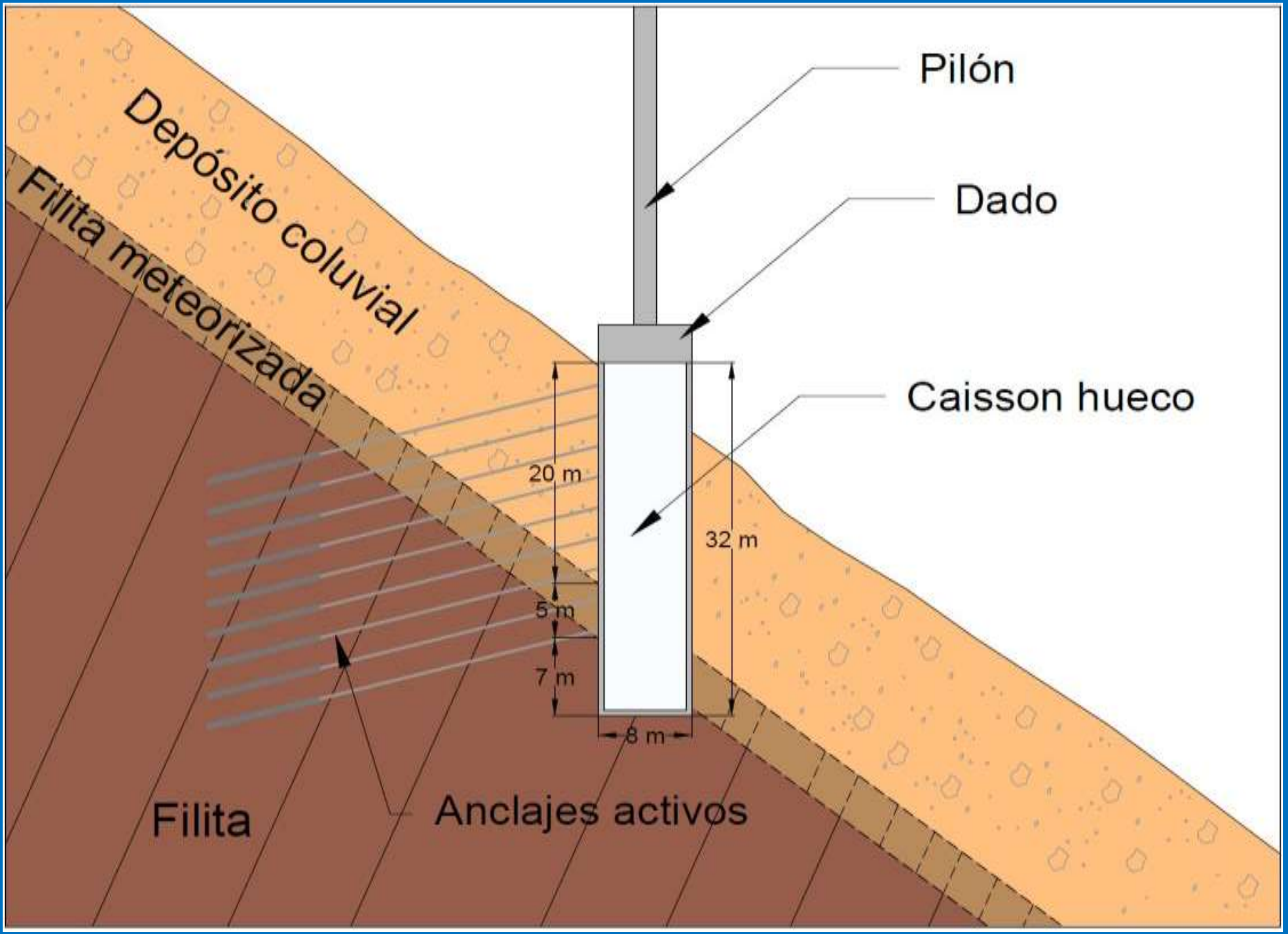
The Chirajara Bridge is built on a foundation of the Phyllites and Quartzite rocks of Guayabetal (PEpgu).
At the Chirajara sector green and purple Phyllites with interlayered Quartzites are found. (Ingeominas 266 plank Villavicencio).
Petrographically corresponds to a micaceous, graphiteous, phyllite lepido porphyroblastic . The basic minerals are muscovite, biotite and graphite .



Phyllites and quartzite fractured and layered schists.

Colluvium Deposit 20 meters thick.

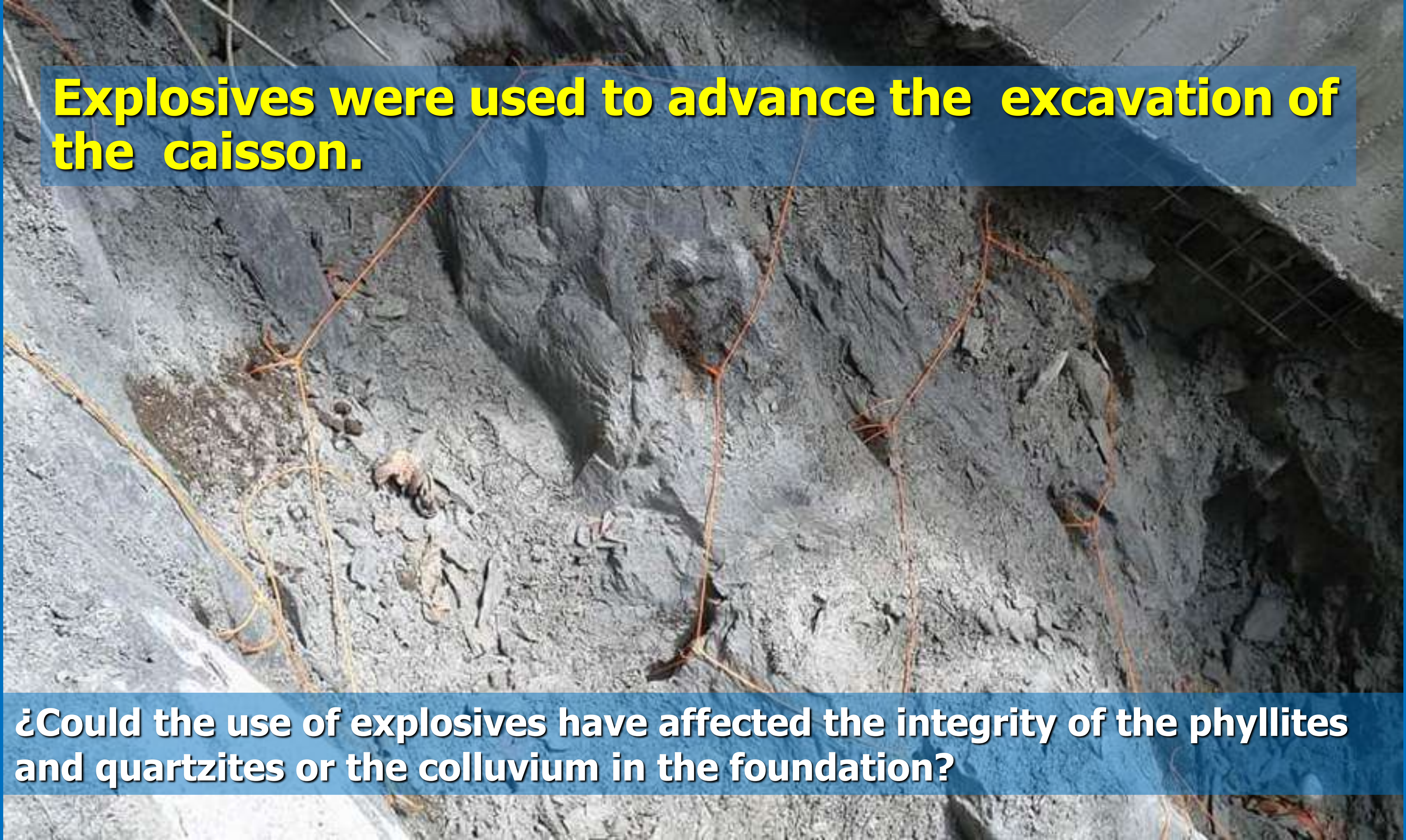
At the site of the right tower (the one that collapsed) exists a Colluvium deposit 20 meters thick.



Each pylon was supported on “individual” caissons of approximately 8 meters diameter.

One single caisson at each pylon

The way it was built: One single caisson provides enough rigidity to the foundation ?

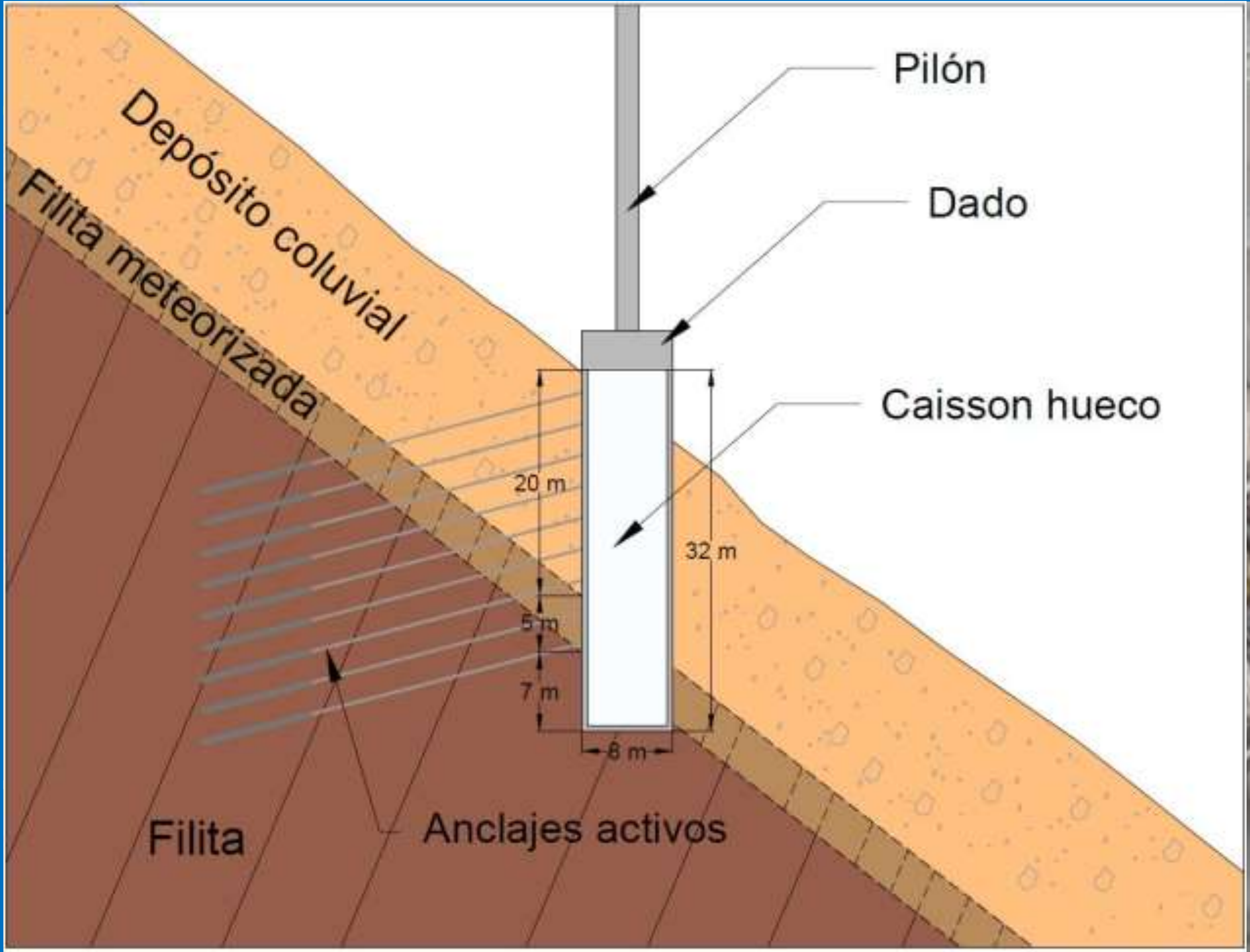


Explosives were used to advance the excavation of the caisson.

¿Could the use of explosives have affected the integrity of the phyllites and quartzites or the colluvium in the foundation?

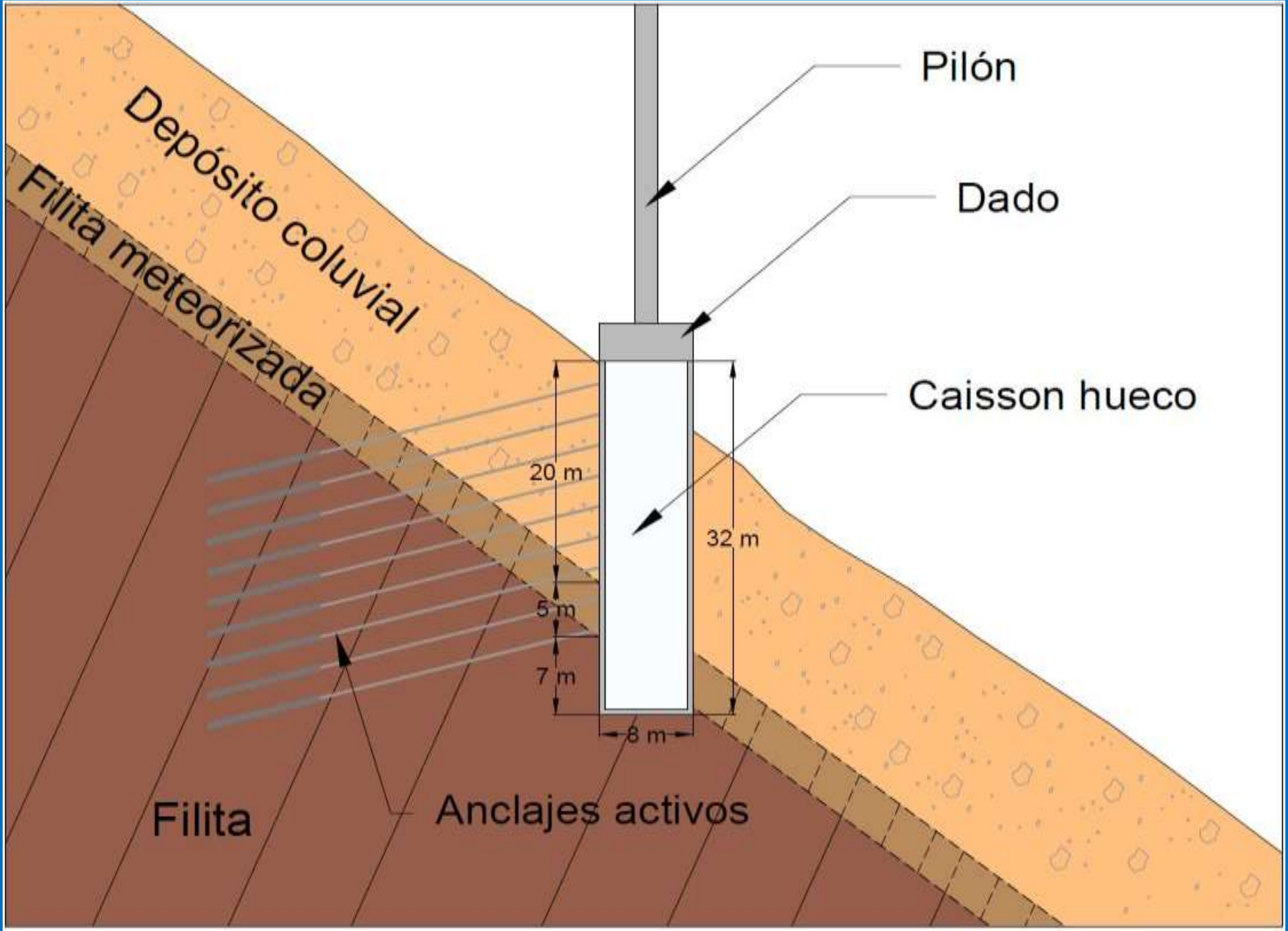
Tie-backs were installed at the top of the caisson into the hill slope.

To counteract the effect of the colluvium against the caisson 9 tiers of 50 tons nominal load/anchor, tie-backs were installed over the top 20 meters of the 32 meters deep hollow caisson.

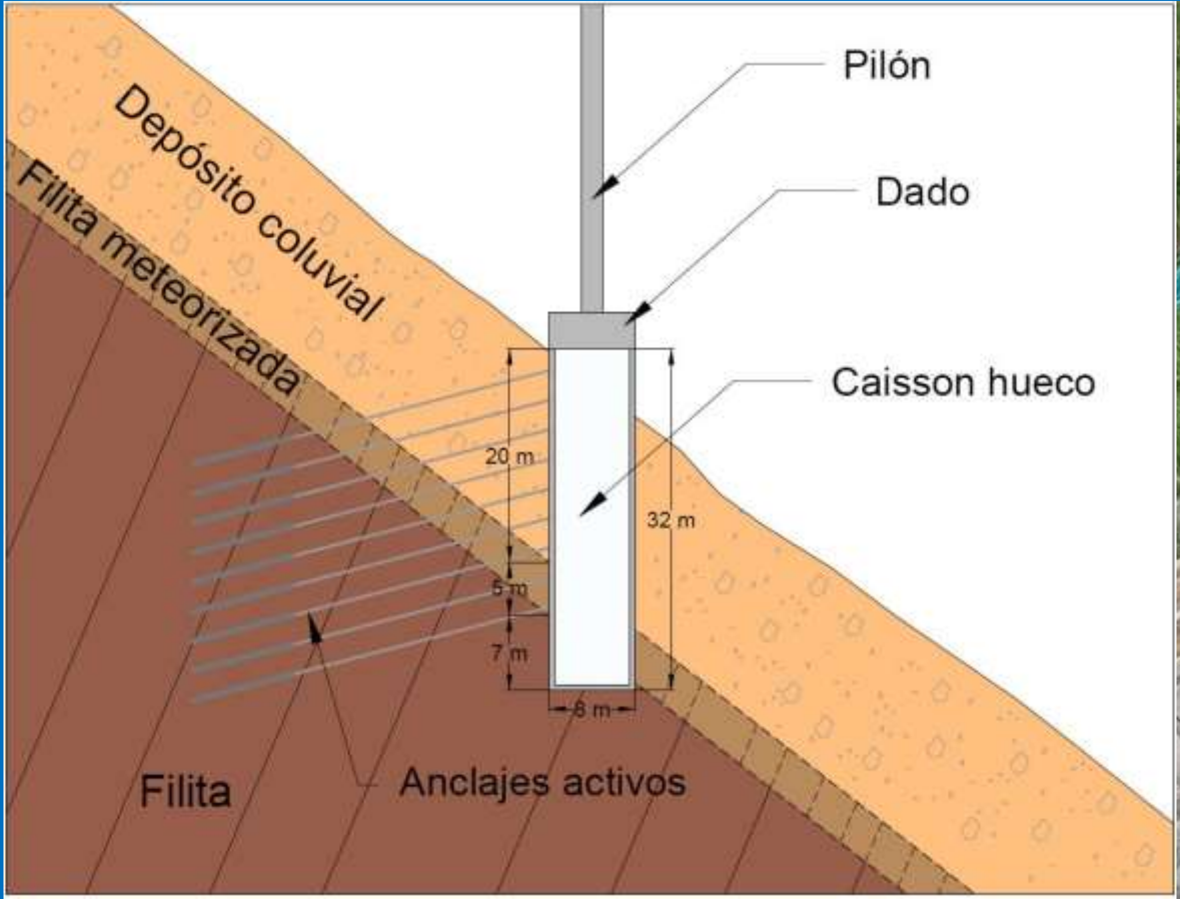


The caisson works as a tie-back anchored bulkhead to retain the colluvium.

In the conditions of the colluvium middle of hillside, is it possible that some horizontal displacement of the foundation may have occurred ?



What happens to the bridge if some cable losses tension or an anchor that sustains the caisson against the colluvium fails ?



The caisson emerges above the ground surface on the exposed hillslope.

Is the caisson sufficiently confined in the ground?

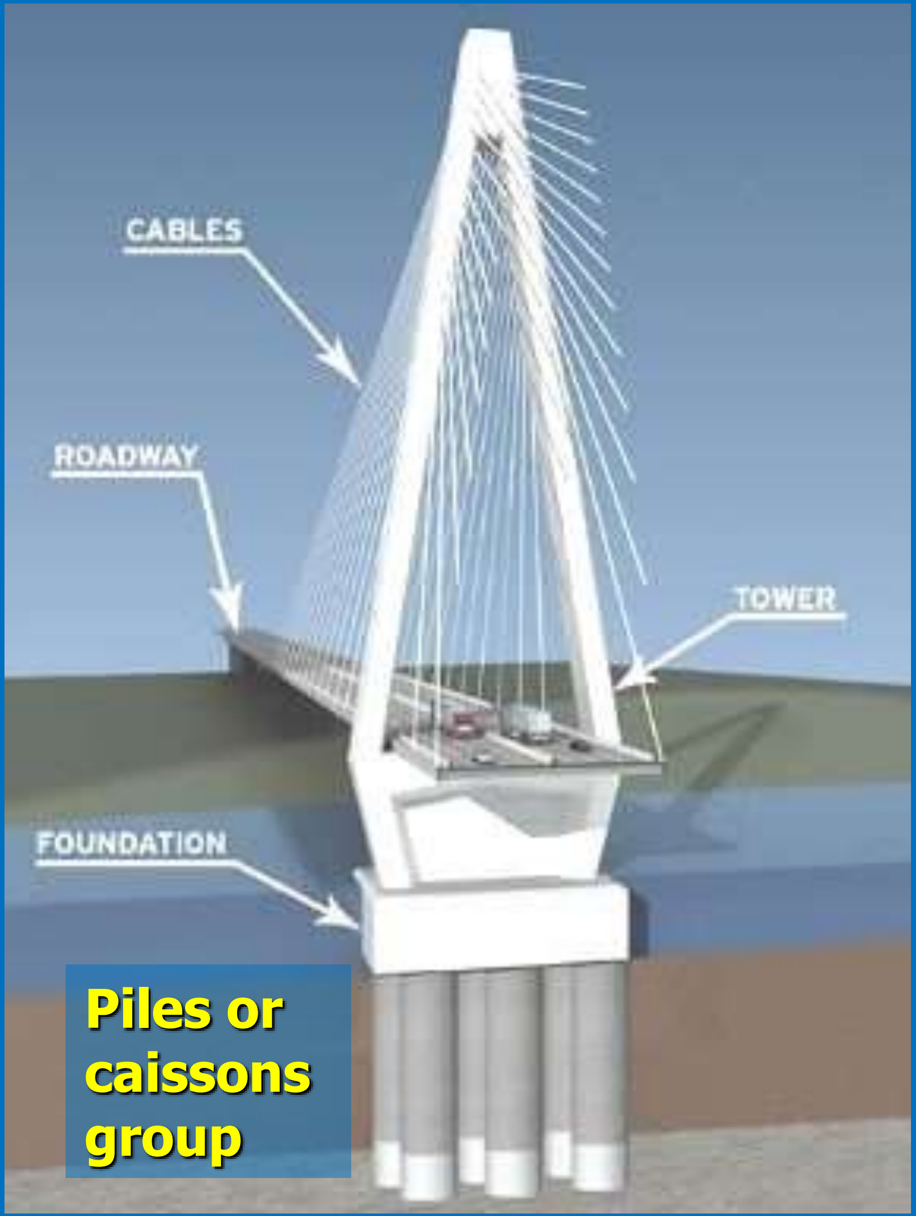
The individual caisson was capped with a cube block and a diamond and pencil tip shaped pylon.

The cube cap of the single caisson was built unconfined above the ground surface.

What is the effect of the non-rigid foundation support?

Non-rigid support

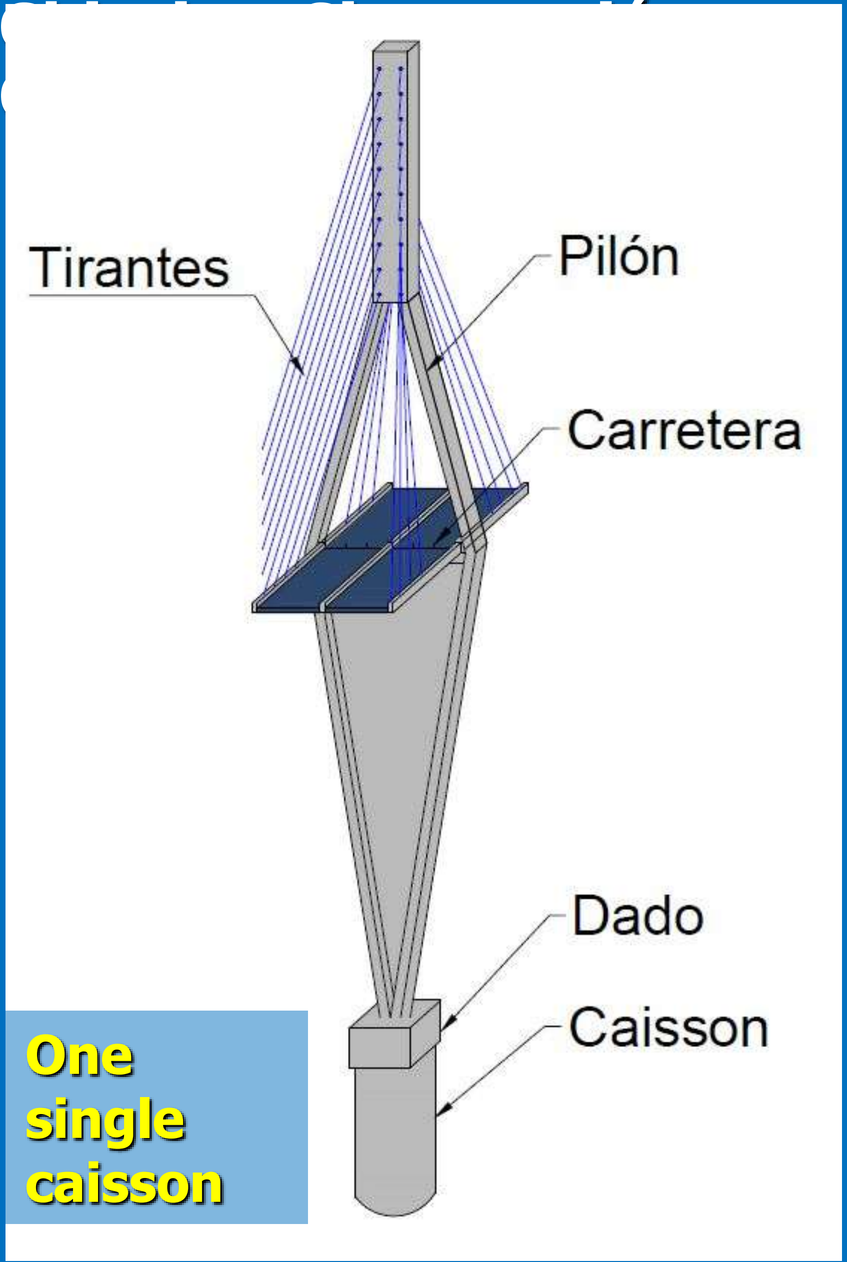
Typical foundation of the pylon (tower) in a cable stayed bridge.



Piles or caissons group

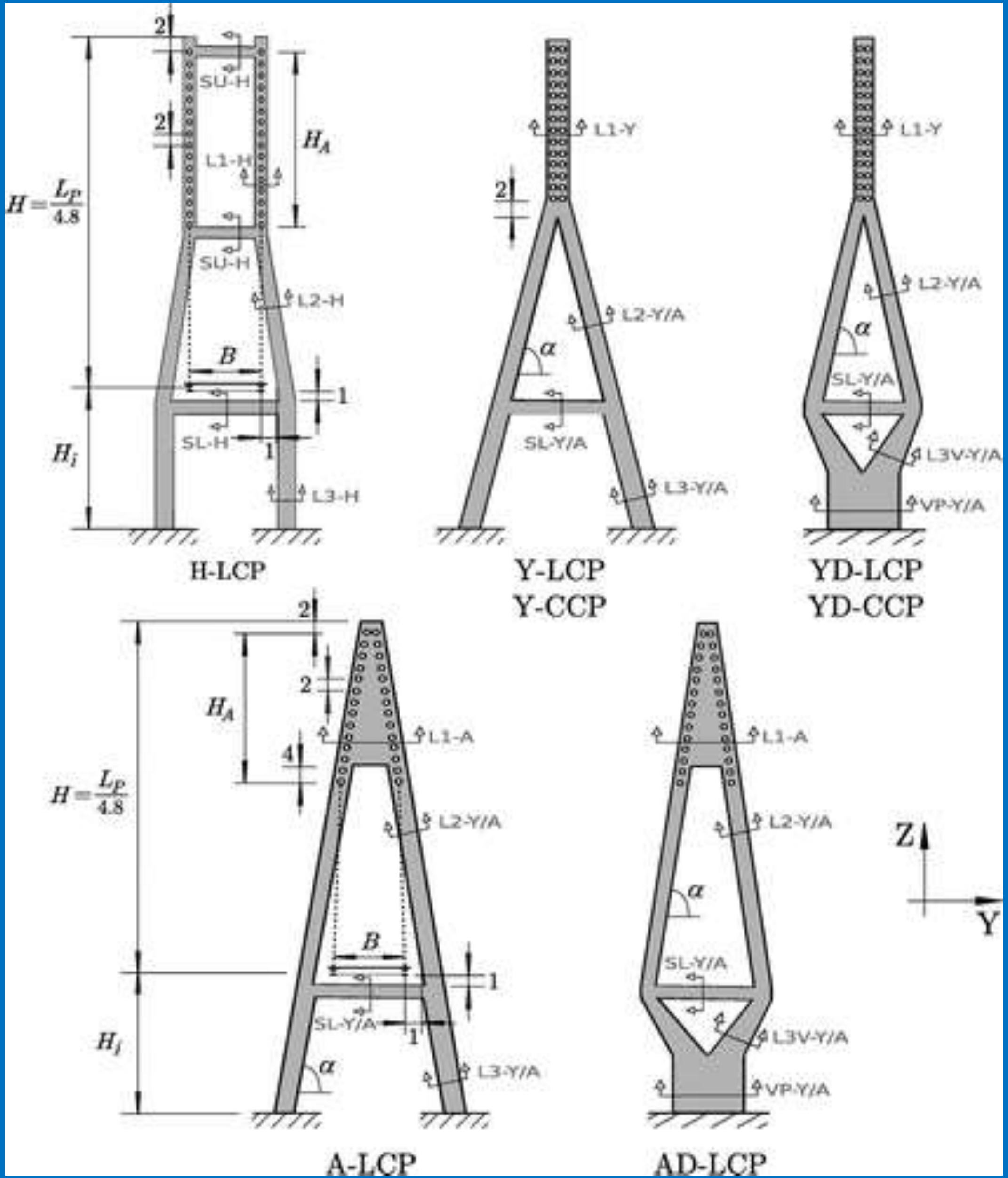
The foundation must work as a fix point to minimize the buckling effect.

Foundation at Chirajara

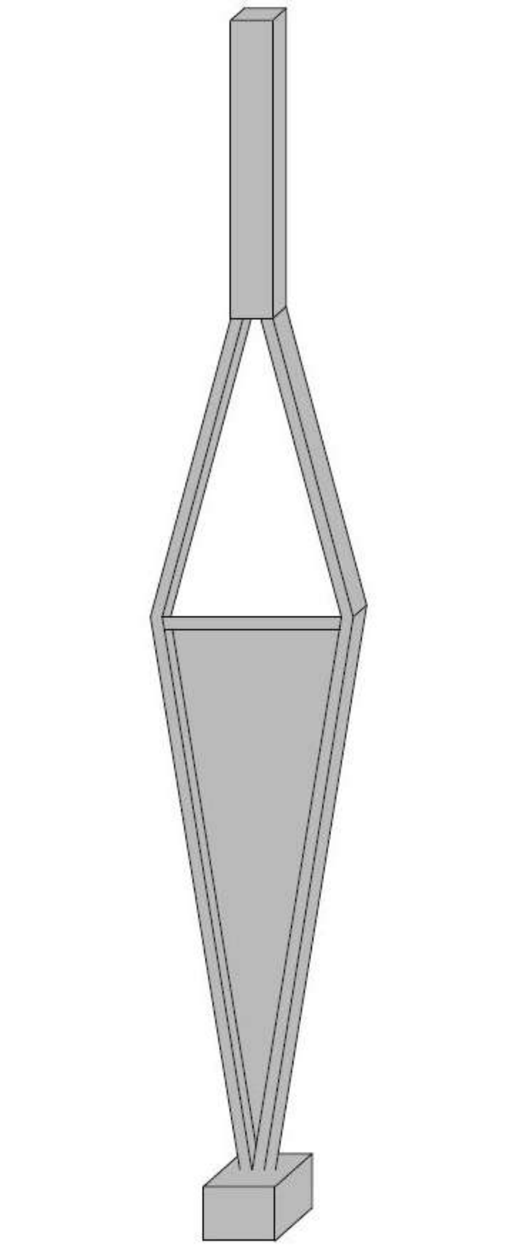


One single caisson

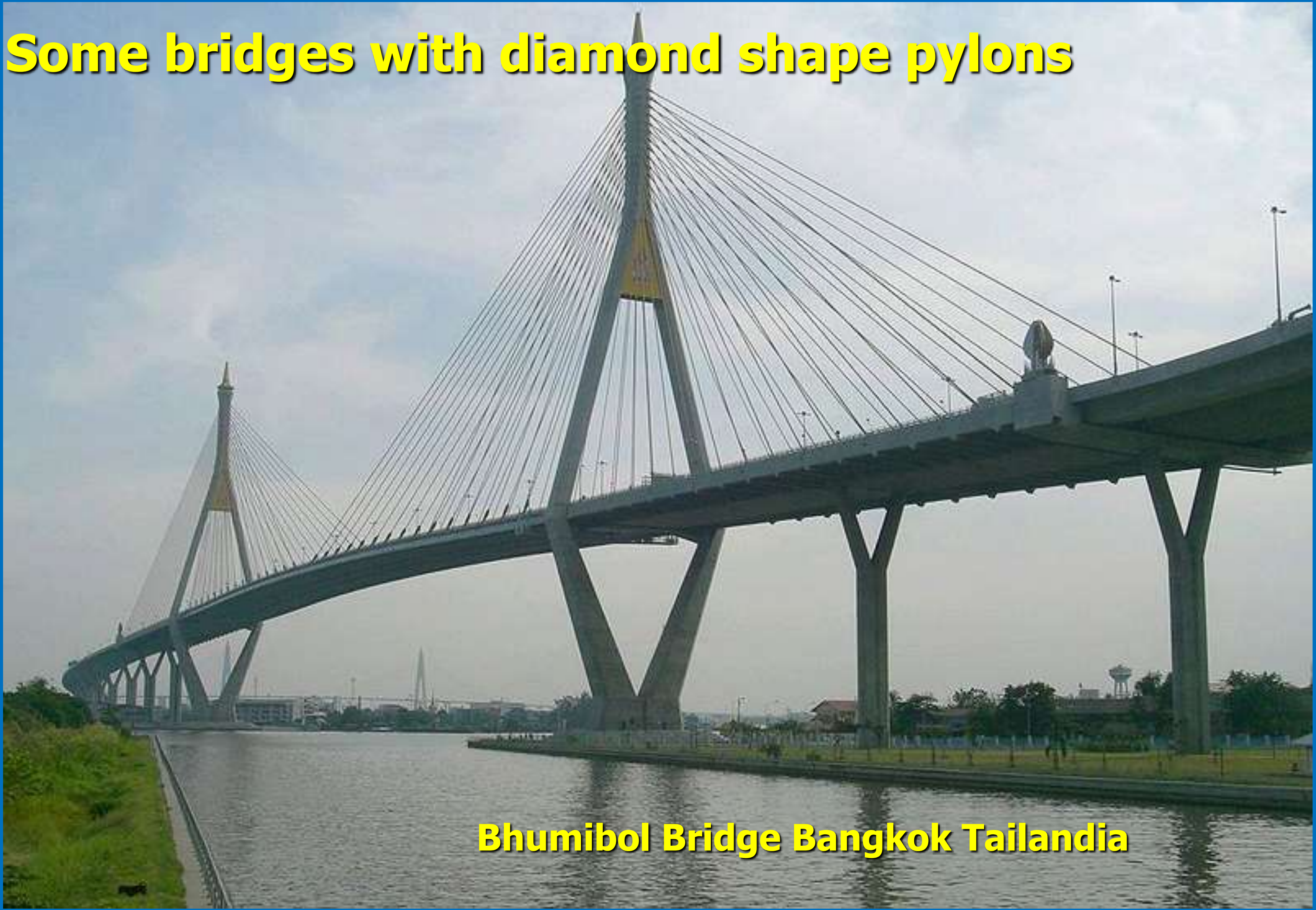
Typical pylon shapes



Pylon shape at Chirajara



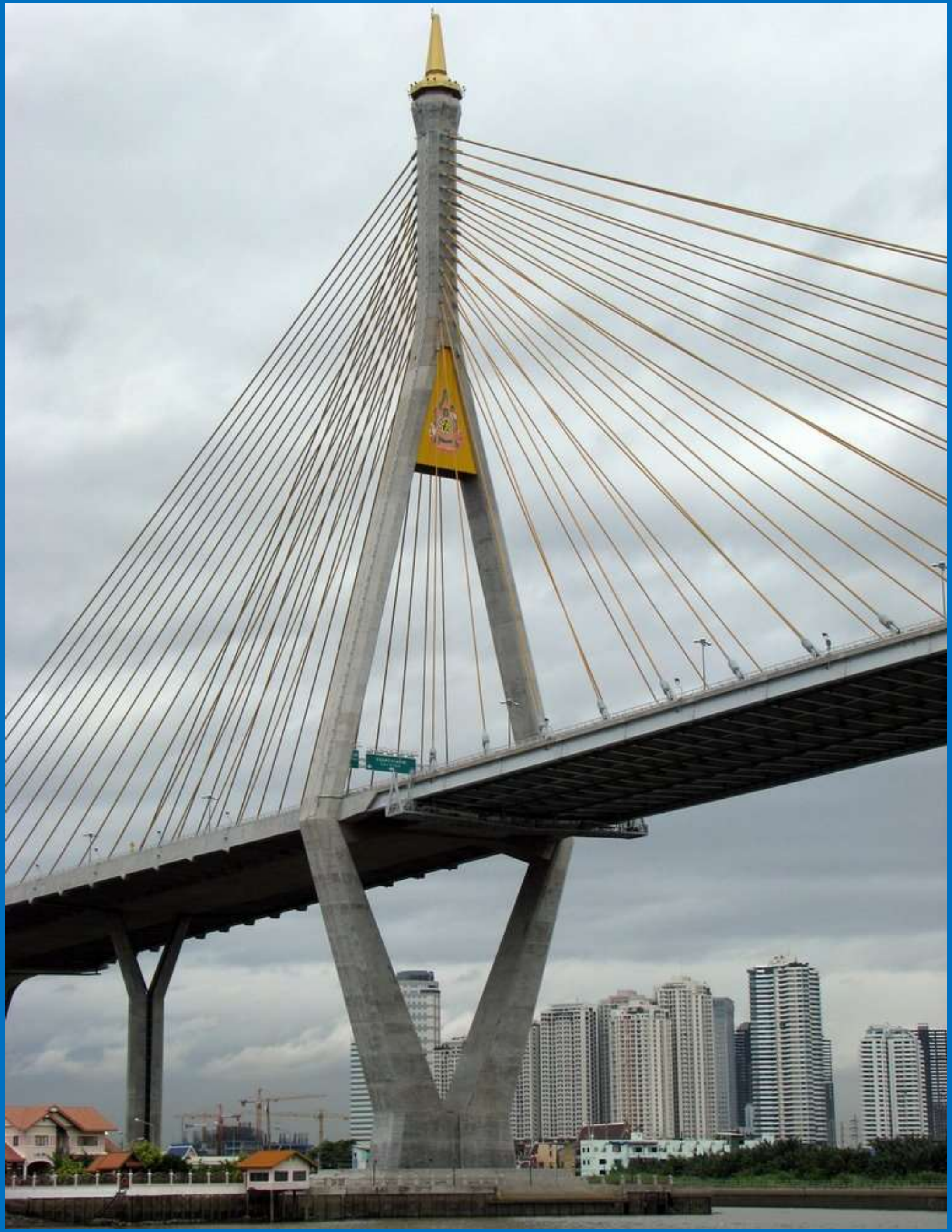
Some bridges with diamond shape pylons



Bhumibol Bridge Bangkok Tailandia


Anqing Railway Bridge

Chao Phraya River Mega Bridge

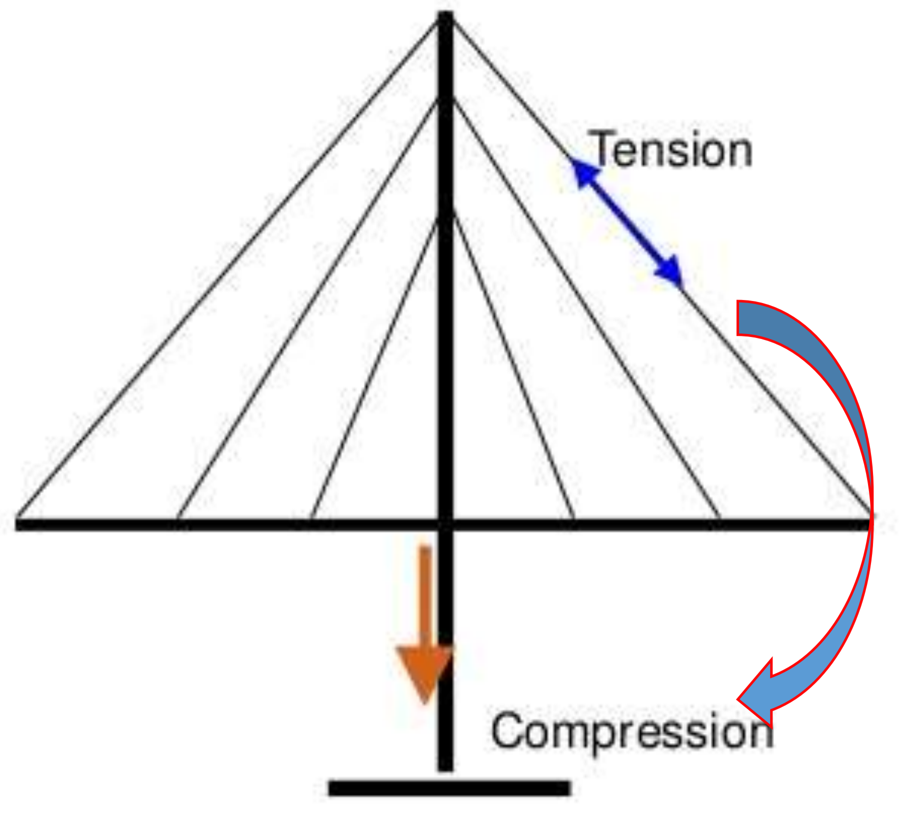



Malinghe Guizhou China

Shanghai's Xupu Bridge

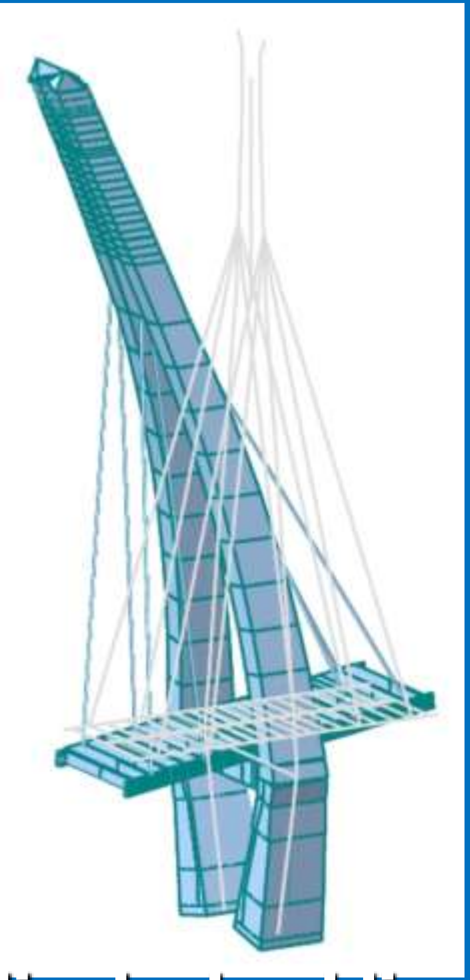

Edong Bridge

Stress on the pylon is mainly compressive and compresion may induce buckling.

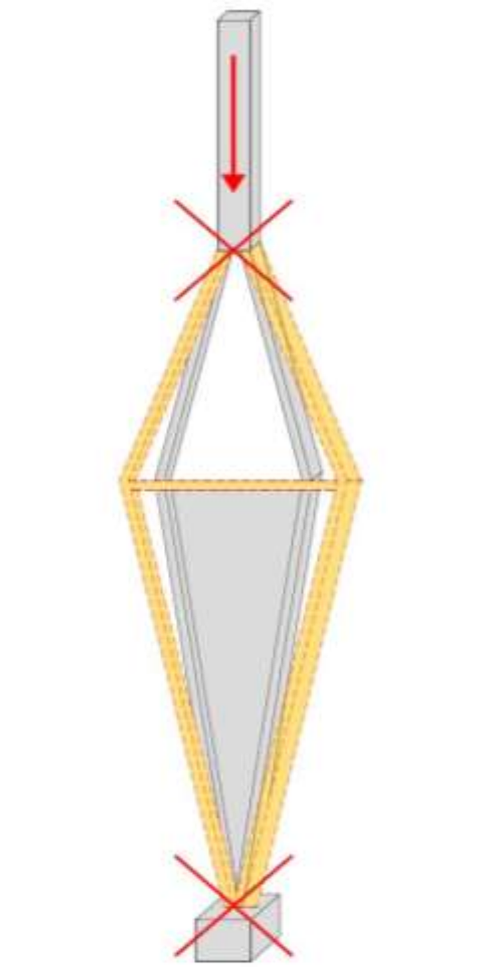


The shape and litheness of the pylon at Chirajara prompted it to fail by buckling?

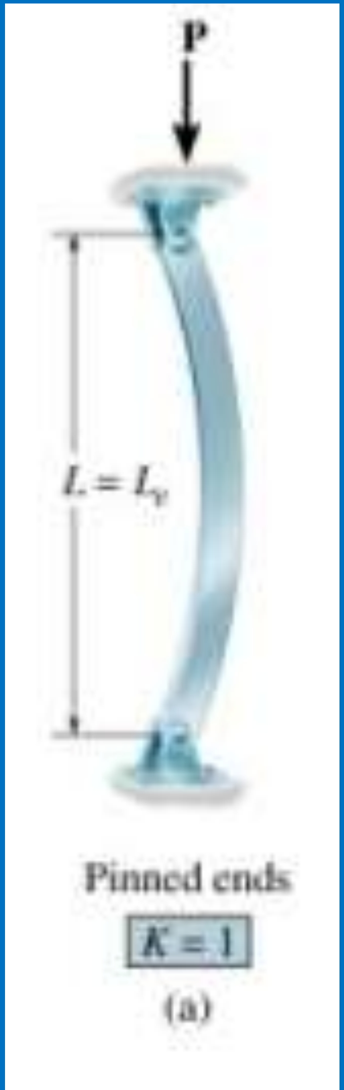
Compression develops "buckling" stress on the pylon.

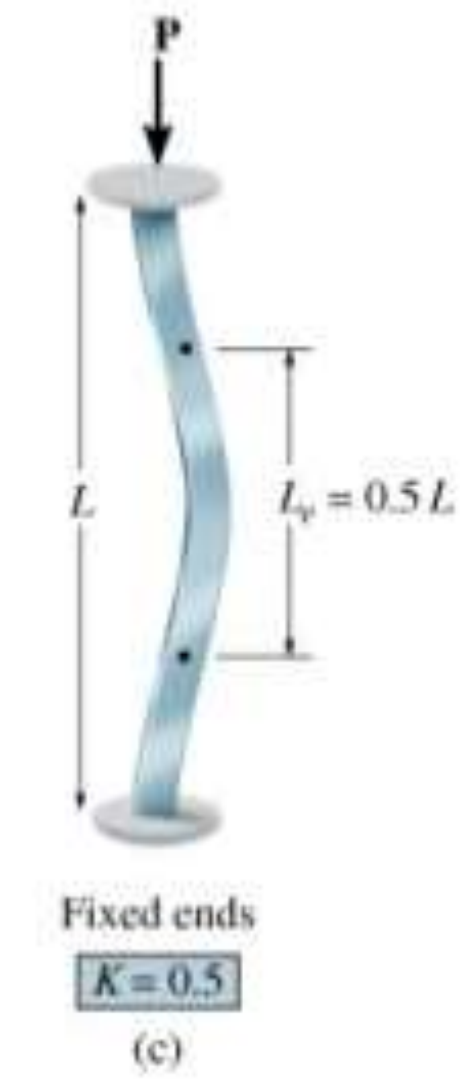


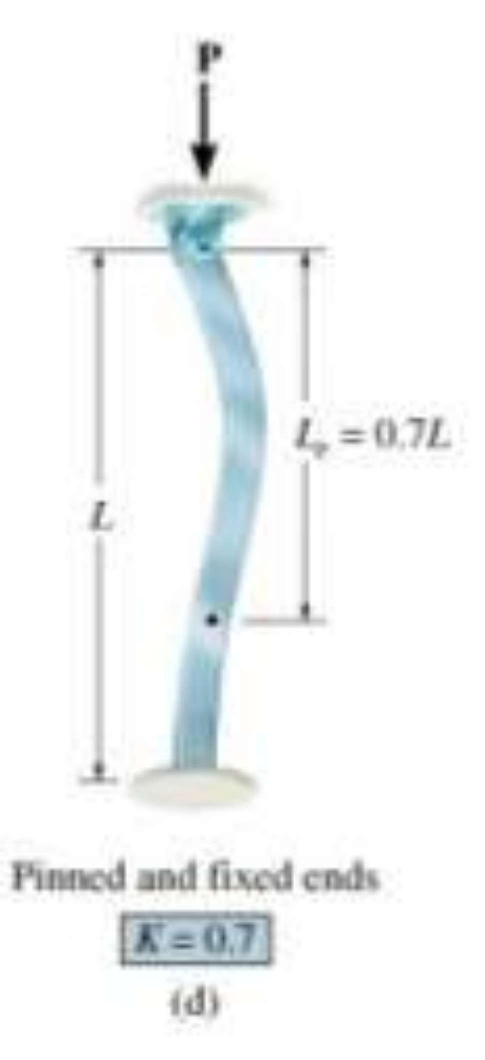
Longitudinal buckling by compression and torsion.



Transversal buckling by compression.

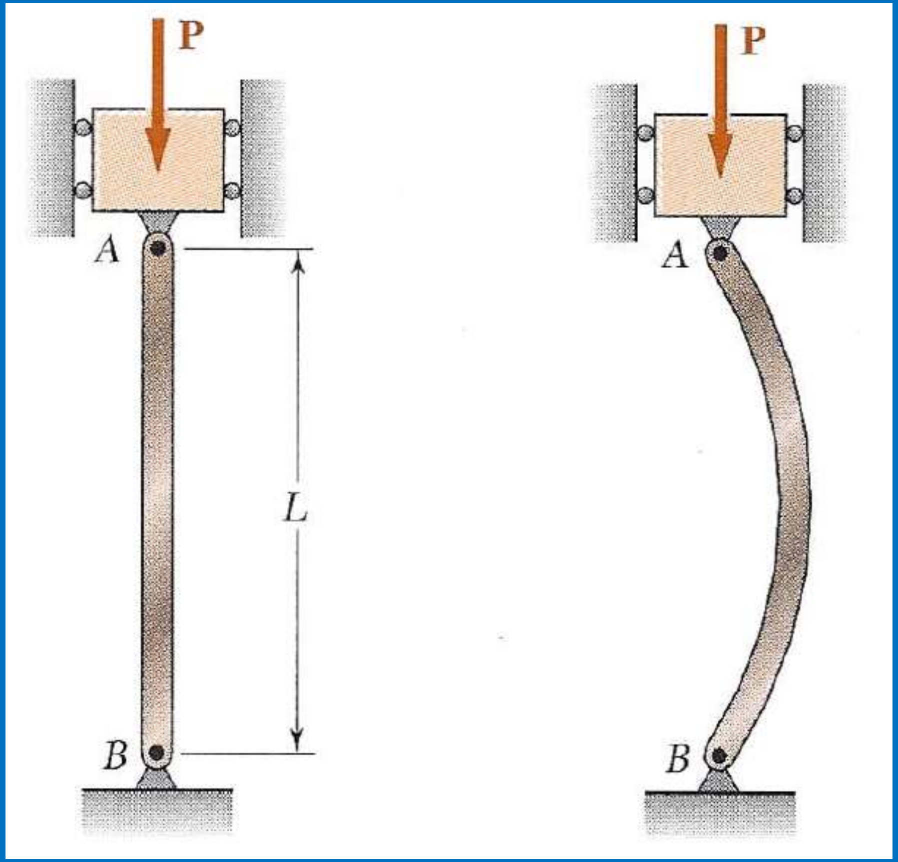




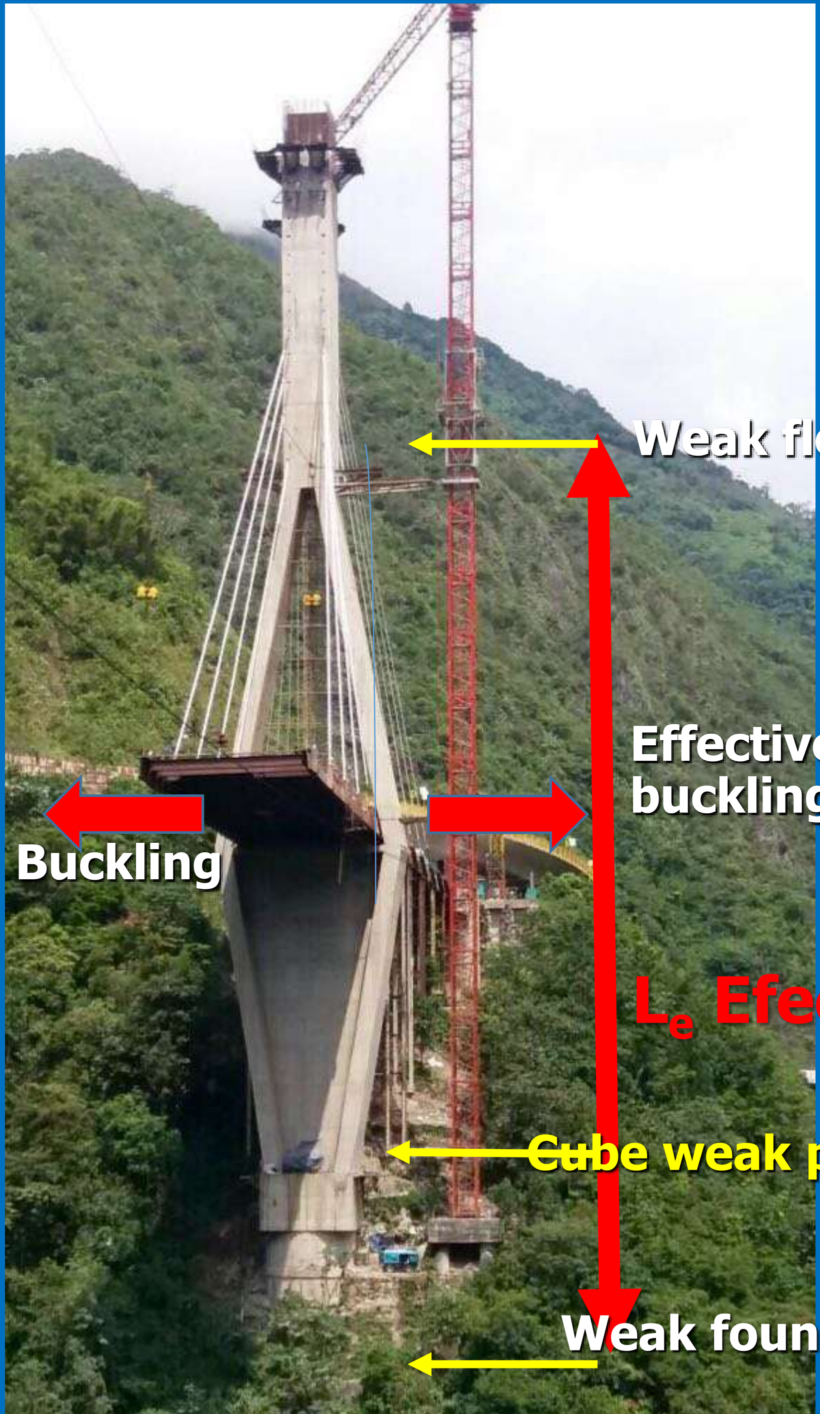


The rigidity of the upper and lower end supports of a column determine its effective lenght for buckling.

The shape of the pylon and the foundation conditions determine the effective lenght for buckling.



Greater L_e greater the buckling



Increased compression overcomes the pylon’s critical capacity, the weak upper and lower points break and the buckling failure is launched.

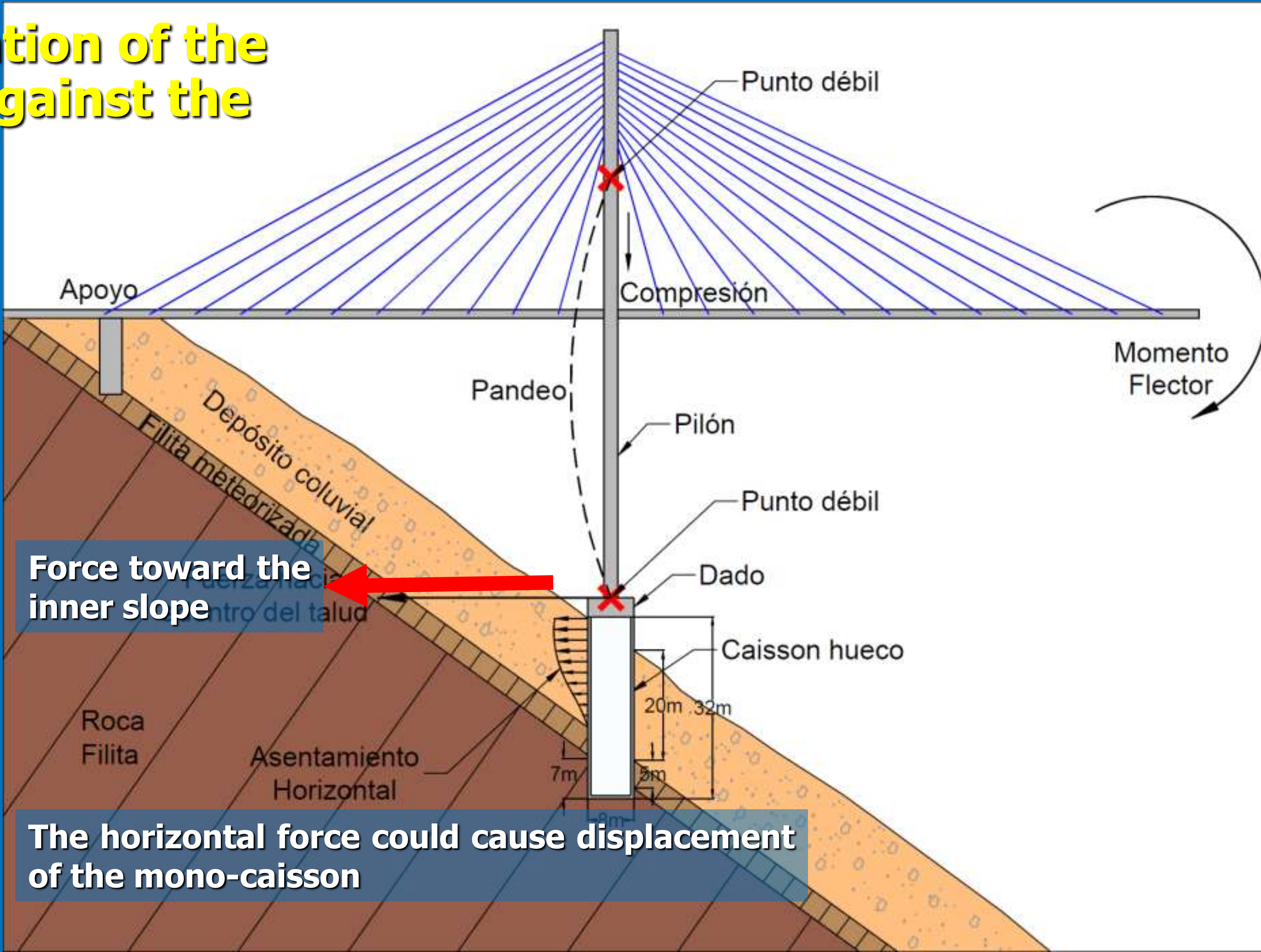
The leaning of the pylon may intuitively suggest that the first to break was the weak foundation point.

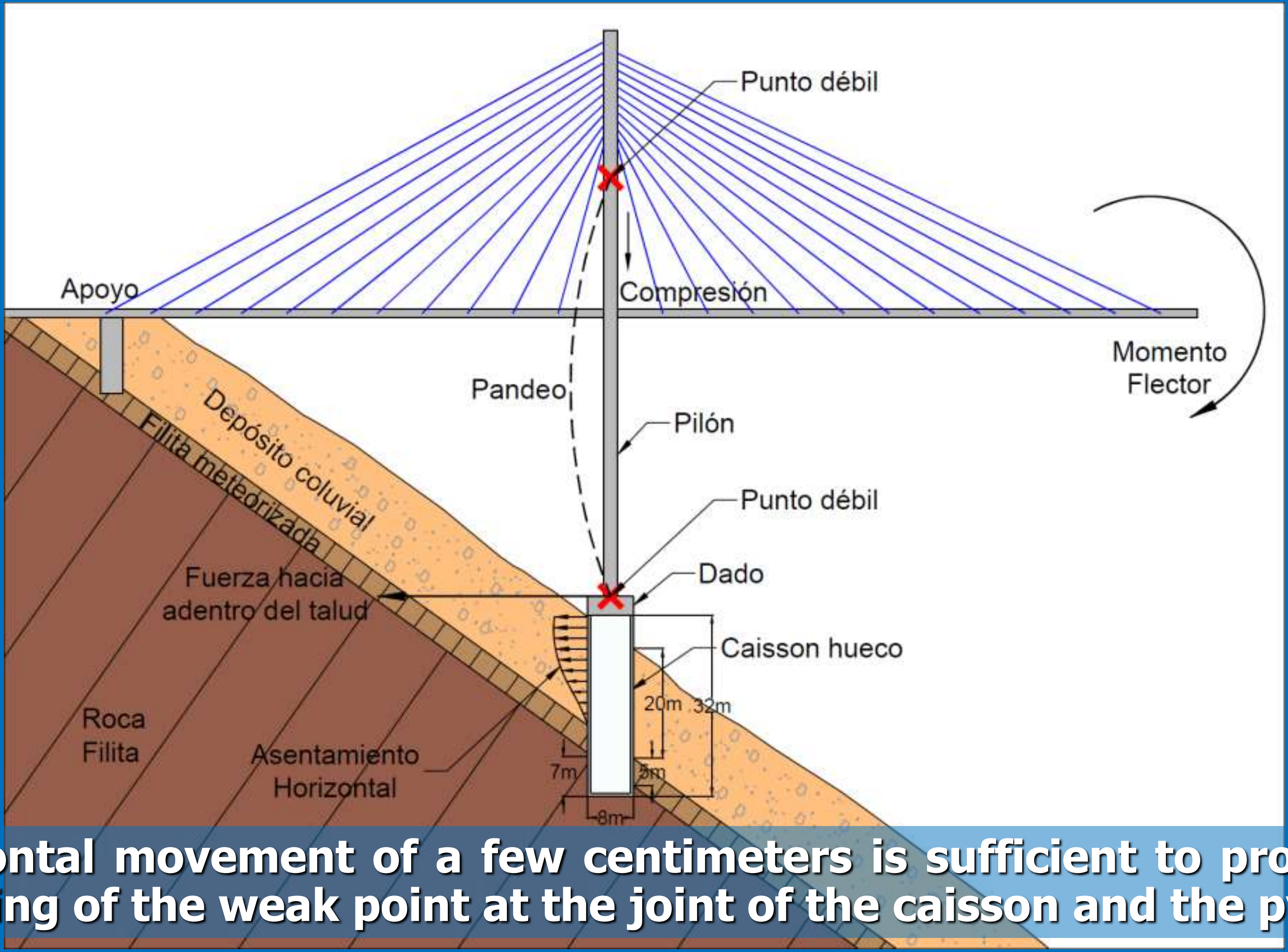
Bending moment failure at the joint between the column and the cube caisson cap.

There is no visual evidence of any movement of the foundation. However, it is not known if any displacement of a few centimeters may have occurred.

Lateral deformation of the mono-caisson against the colluvium?

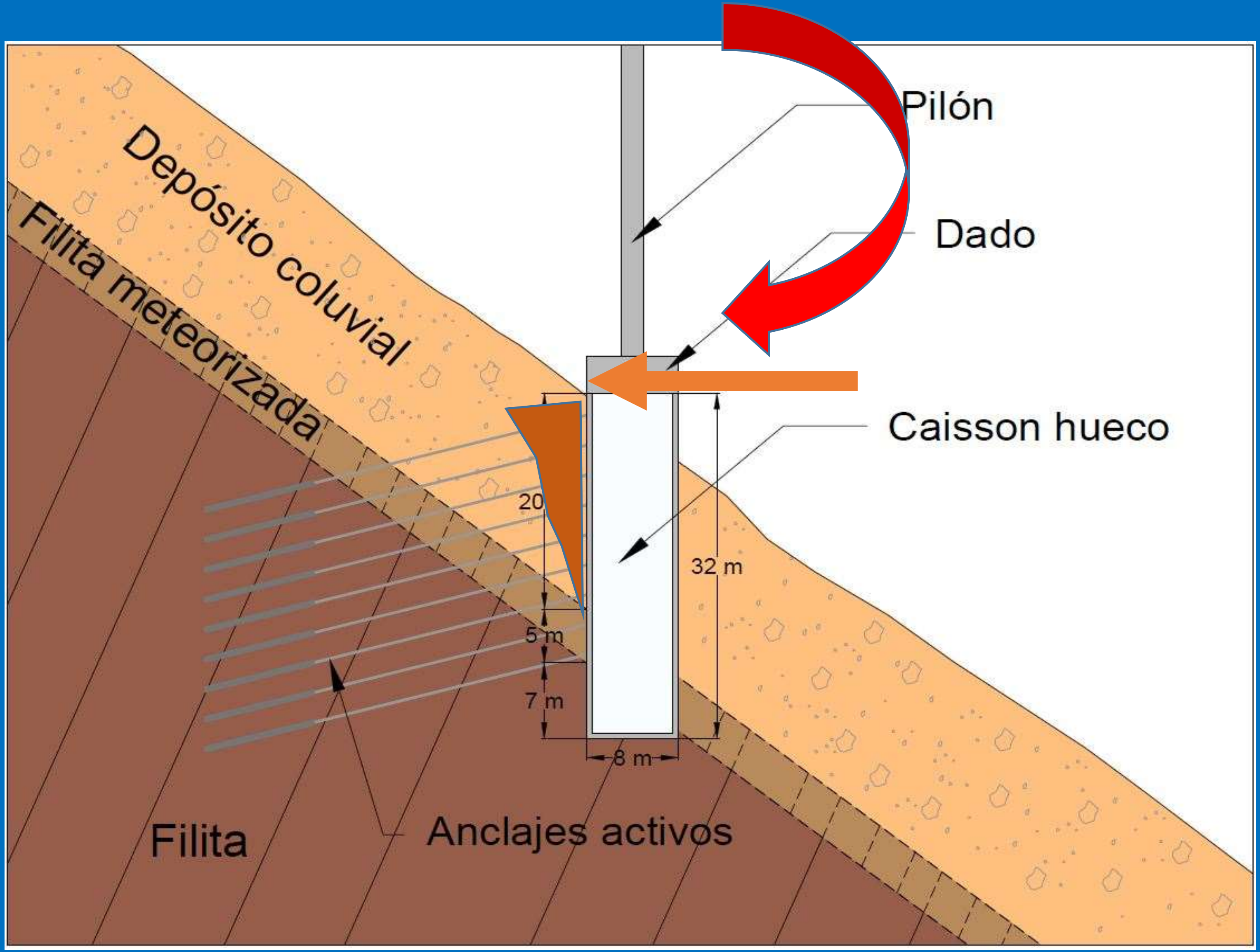
The bending moment generates a horizontal force at the semi-rigid point of the joint between the pylon and the foundation





Horizontal movement of a few centimeters is sufficient to produce the breaking of the weak point at the joint of the caisson and the pylon.

The assumption of a possible movement of the foundation could be challenged or confirmed if an investigation of the top tiers of tie-backs indicates loss of tension.



Graphic composition of how the pylon components came to rest after the collapse.

Graphic composition produced by Christian Hernandez Amaya.
(las dos orillas.co)

" Columns 1 to 4 conformed the diamond, 5 was a horizontal cross brace beam, 6 was a concrete diaphragm wall that filled the lower part of the diamond, and supported 5. 7 is the lower end of the tower. The colored lines highlight the unions between the walll and the lower columns of the diamond. The base (with cube shape} that supported the tower was left in place virtually intact. "

Explanation of the structural failure according to the project Inspector.

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FIRST TECHNICAL SPECIALTY ANALYSIS OF THE POSSIBLE CAUSES FOR THE COLLAPSE OF THE CHIRAJARA BRIDGE.

FIRST WORKING HYPOTHESIS

Generally speaking, cable stayed bridges having "diamond" shaped towers can offer more than one type of failure.

1. Failure by lack of Tension capacity in the cross "bracing" beam and diaphragm wall due to the change in direction of the load that descend on the tower columns because of its "diamond" shaped geometry.

This is the main hypothesis in the CHIRAJARA case since very little prestress was observed in the cross "bracing" beam and scarce tension reinforcement in the diaphragm wall in the direction parallel to the cross bracing beam.

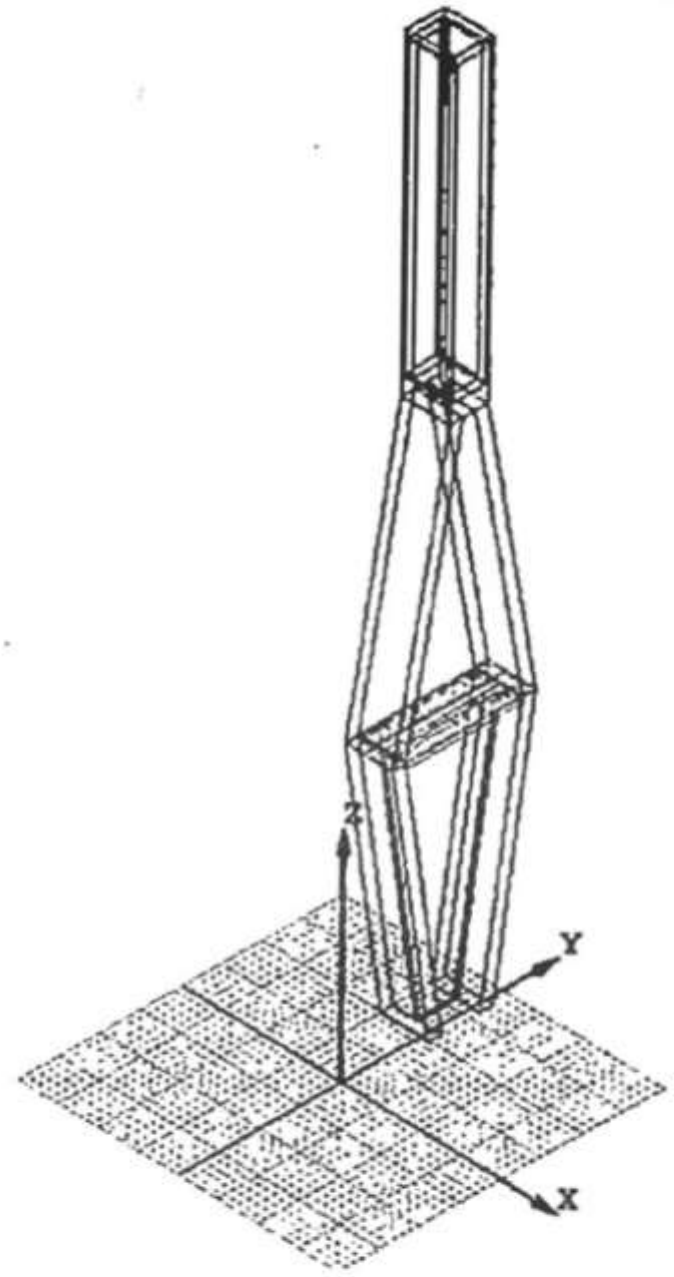
It can be observed in the videos that the lower columns break apart from the connection with the bracing slab followed by the breakage of the connection with the diaphragm wall thus causing the collapse of the tower and its cantilevered roadway deck.

2. Soil failure due to lack of bearing capacity or instability of the side hill slope causing potential settlement of the tower.

There is not evidence of this condition in the CHIRAJARA case since it is noted that the foundation remained intact even after the collapse.

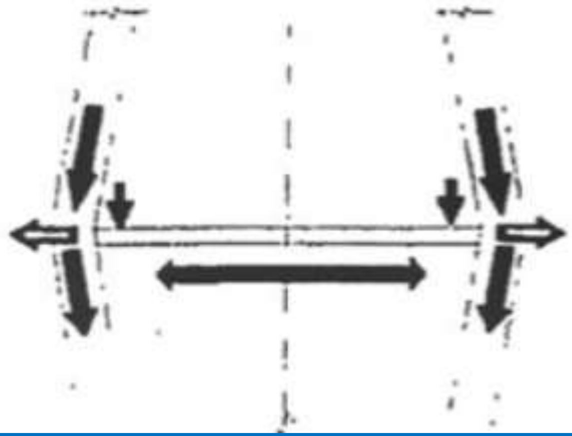
3. Failure due to lack of capacity of the stay cables or its anchors due to overloading.

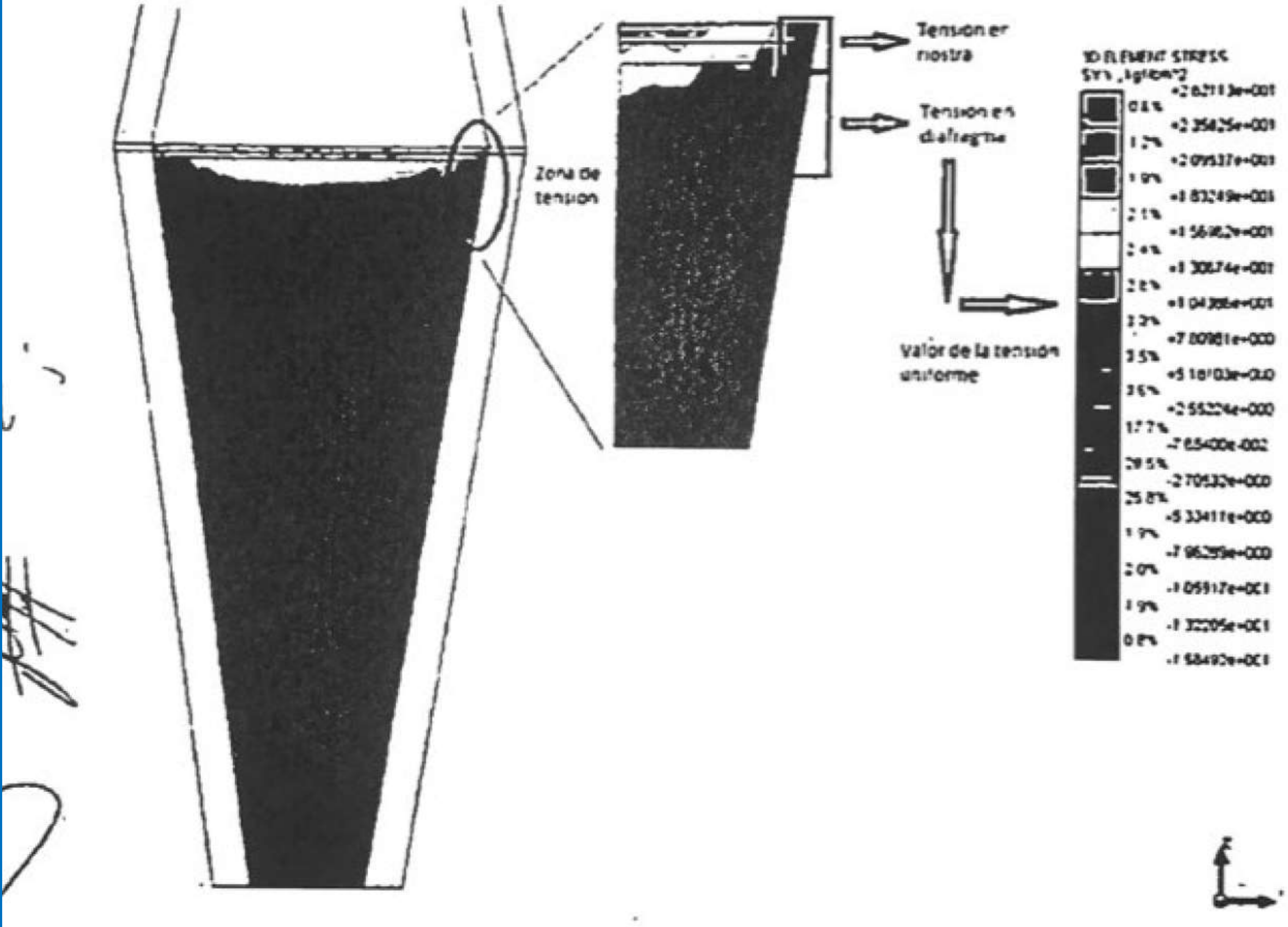
There is no evidence of this condition in the CHIRAJARA case since no tearing of the cables was observed prior to the failure of the tower. In fact, it is observed that at the start of the tower failure the cables loose tension and fall altogether with the road deck.



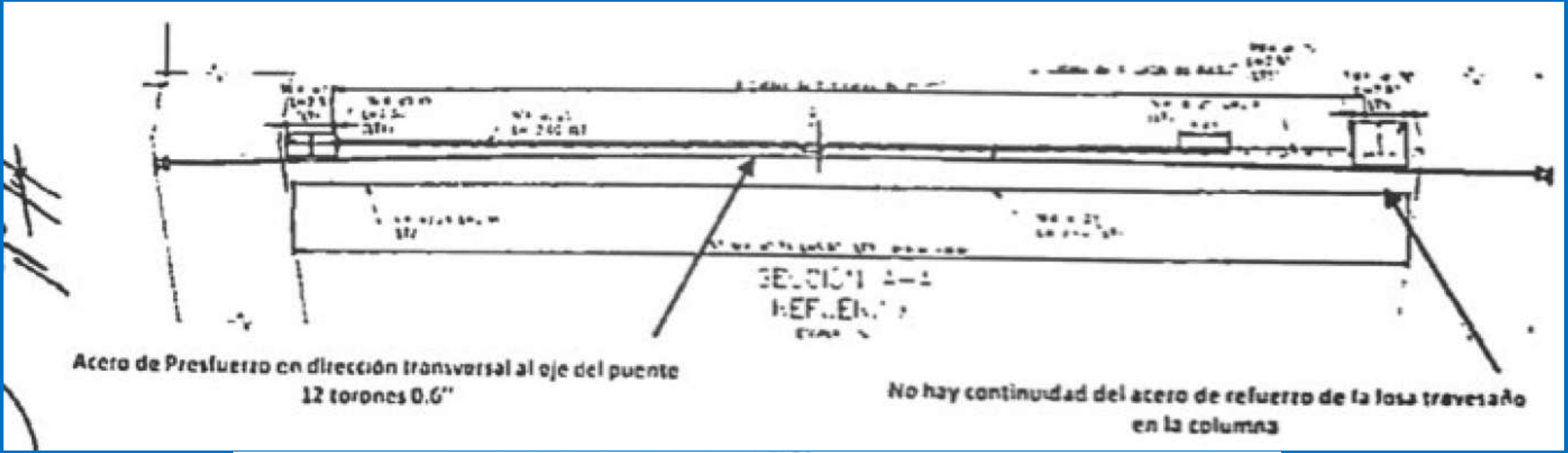
Ejes de referencia del modelo

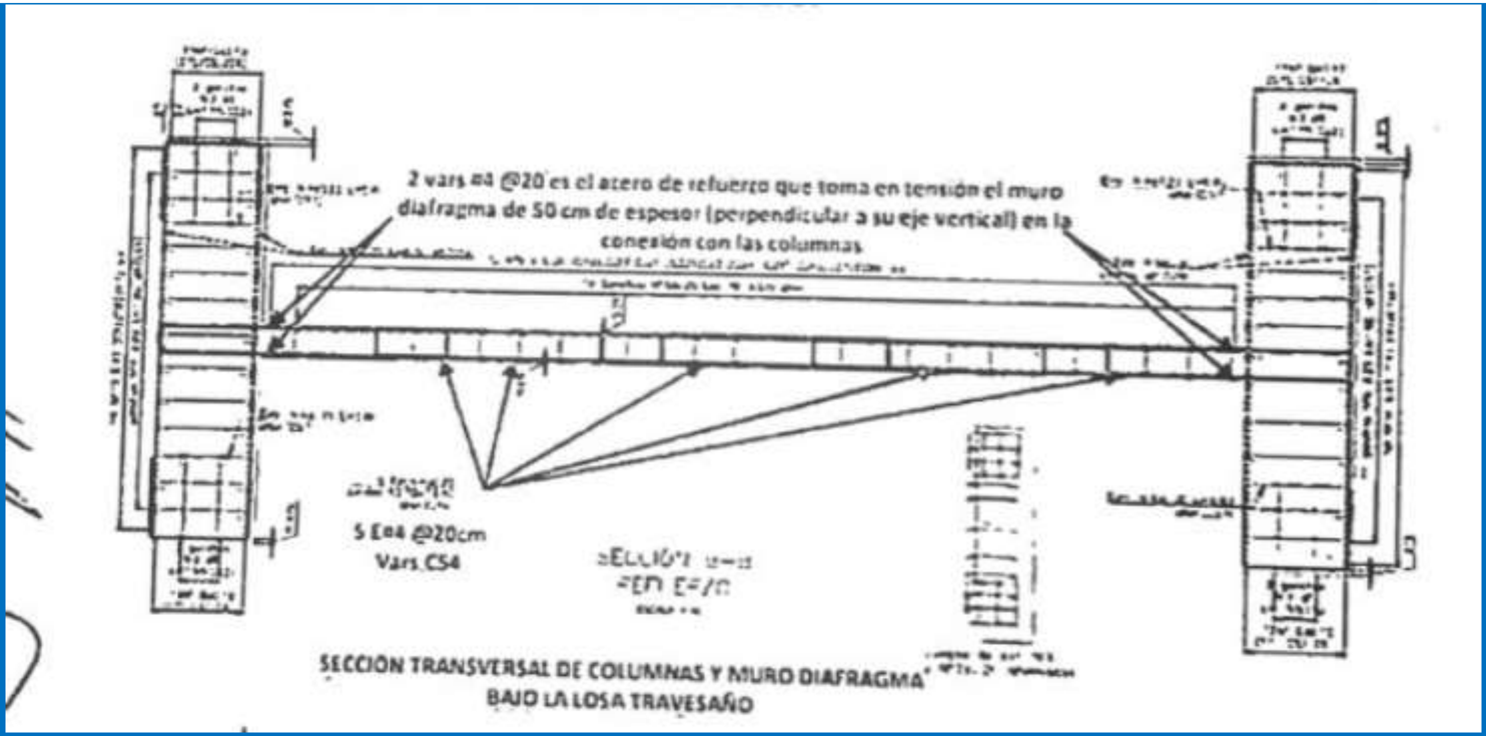
Para mejor comprensión de los esfuerzos obtenidos en la zona de interés se muestran los esfuerzos en la dirección YY que corresponde al eje transversal al puente o al eje longitudinal de la losa travesaño





Distribución de esfuerzos en muro diafragma y riostra (losa travesaño)


Acero de Presfuerzo en dirección transversal al eje del puente
12 torones 0.6"
No hay continuidad del acero de refuerzo de la losa travesaño
en la columna


2 vars #4 @20 es el acero de refuerzo que toma en tensión el muro diafragma de 50 cm de espesor (perpendicular a su eje vertical) en la conexión con las columnas
5 E#4 @20cm
Vars.CS4
SECCIÓN TRANSVERSAL DE COLUMNAS Y MURO DIAFRAGMA
BAJO LA LOSA TRAVESAÑO

The cross-brace horizontal beam

Horizontal reinforcement cables

W radio

Fracture in the vertical diaphragm wall of the existing pylon

What’s next?

What is important is not finding the guilty

If we learn from this failure and improve our engineering we will not repeat this traumatic experience.

Thank You

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