Underpinning, a calculated approach

A presentations intended to provide some useful pointers for engineering calculations of pin-underpinning consistent with the provisions of the new 2014 Building Code

Dan Eschenasy, PE, F.SEI

Department Chief Structural Engineer

Underpinning

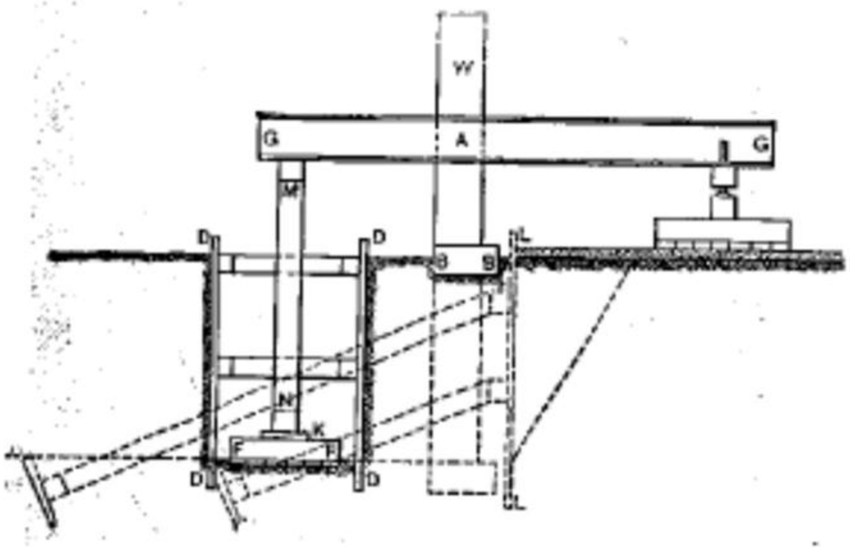
Pit?

Pier?

Continuous strip?

Pin?

Classical?



FOUNDATION UNDERPINNING AS IT WAS RECOMMENDED IN MANUALS AROUND 1910 – SUPPORT OF SOIL SYSTEM WAS SEPARATE FROM UNDERPINNING

PIN- Underpinning

The following slides look to the engineering calculations aspect of pin underpinning operation and provide some suggestions consistent with the new 2014 code provisions..

Underpinning consists in the installation of a new foundation under an existing one.

These new permanent foundations are installed to support "adjoining walls" or "adjoining buildings". [Adjoining generally means adjoining to excavations, not necessarily on a different lot.]

Pin-underpinning is a particular method of underpinning that includes support of excavation – sometimes a temporary function. This method is so commonly used in NYC that it usually referred as underpinning.

FHWA-RD-75-130
LATERAL SUPPORT SYSTEMS AND

Shoring presents some special problems. First, when old walls are encountered, it is often not possible to shore these walls without reinforcing the footing. In some cases the entire footing must be rebuilt prior to both shoring and underpinning. In extreme cases entire walls have to be rebuilt.

A second consideration is the moment and shear capacity of the walls being underpinned. Asymmetric loading or load concentrations (such as from high capacity underpinning piles) are typical concerns.

Lateral support and/or reinforcement is often necessary to alleviate this type of problem.

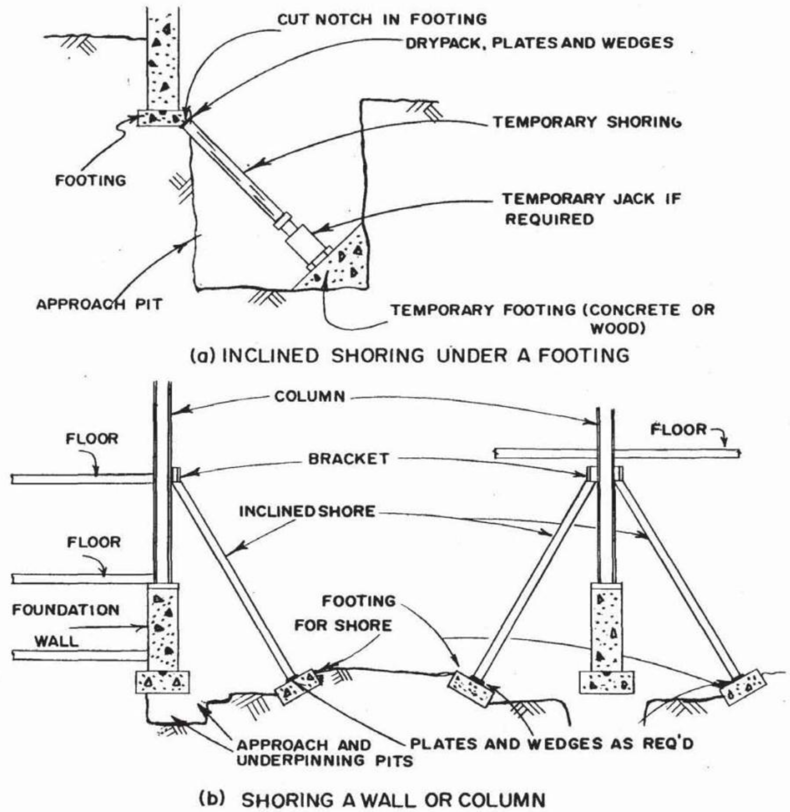


Figure 125. Inclined shoring details.

-328-

Sources of settlements

a. ***Structural Elements**. Settlements may be elastic in nature due to an increase in load. Non-elastic deformations may stem from creep and shrinkage of the concrete used for underpinning, as in pit underpinning.*

*b. **Bearing Stratum**. Settlements are caused by strain within the bearing stratum.*

*c. **Construction Procedures**. The two main sources of settlement during construction are loss of ground during excavation and the strain associated with load transfer.*

*d. **The Structure**. The integrity of the existing structure must be considered. Of special interest are old masonry walls, in which briCk and mortar may have seriously deteriorated, and structural members (both walls and columns) that might not withstand the bending moments induced during load transfer*.

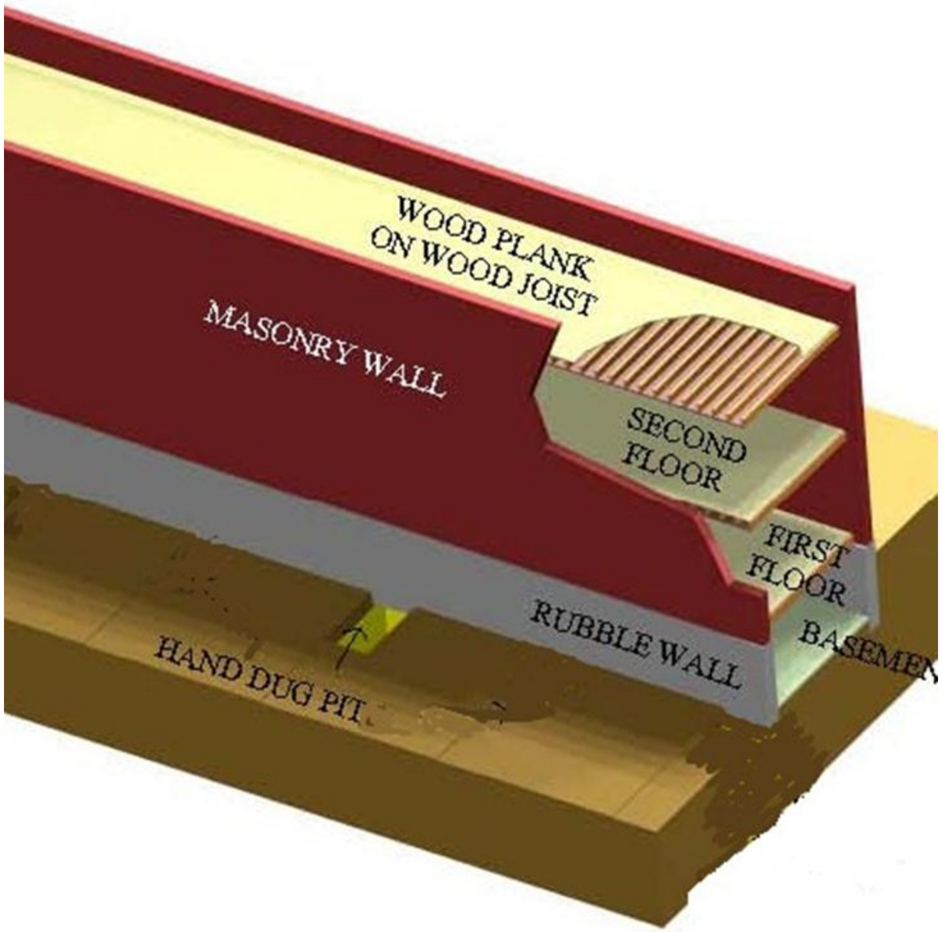
FROM FHWA-RD-75-130

Repeated installation of a single pin?

The installation of a **single pin** is mostly a methodology of execution problem. One needs to consider how much the existing foundation can span unaffected when a hole is dug underneath, how to protect the sides of the approach pit, how to pour and connect the pin to the existing foundation. etc.

The loads introduced by the installed pin will induce only local effects.

The removal of soil for just one pin is not likely to affect the overall pressure on nearby soil.

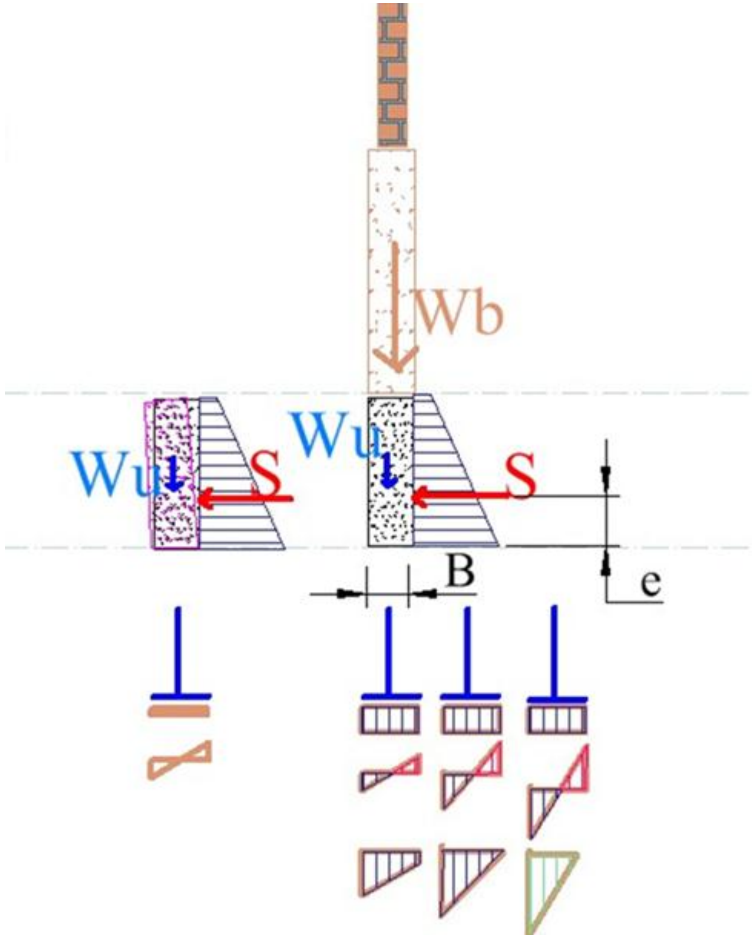


Single pin

As the depth and the corresponding lateral soil pressure S increase, a single pin, will fail by overturning.

The conditions are such that the contractor will not seek to stabilize the pin by increasing the depth of the pin beyond the depth of the existing foundation, B.

When connected at the top the pin will be stabilized by the weigh transmitted down from the existing building.

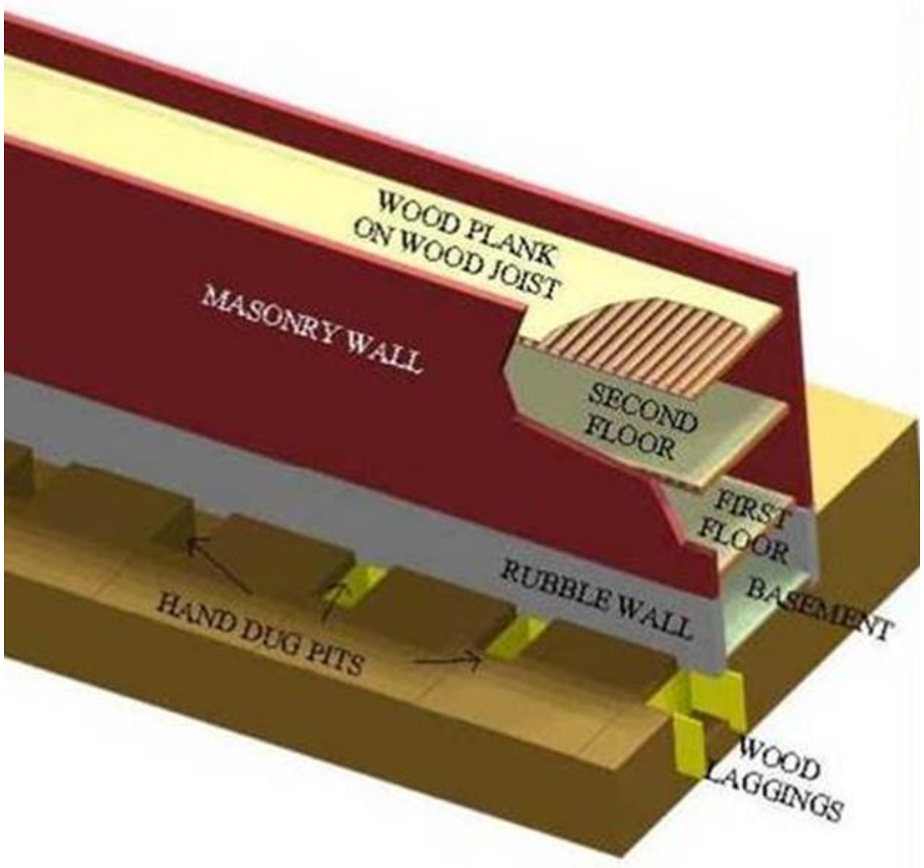


Repeated installation of a single pin?

In many projects the underpinning of an entire wall is viewed as a repeated installation of a single pin.

Unless based on engineering, the simultaneous removal of soil and installation of pins might lead to:

- Increase in the vertical pressure exerted on the underlying soil, sometimes beyond allowable values.
- Effects of the lateral soil pressure will additionally increase the vertical pressure on the underlying soil.
- The soil lateral pressure will affect locally the existing building.

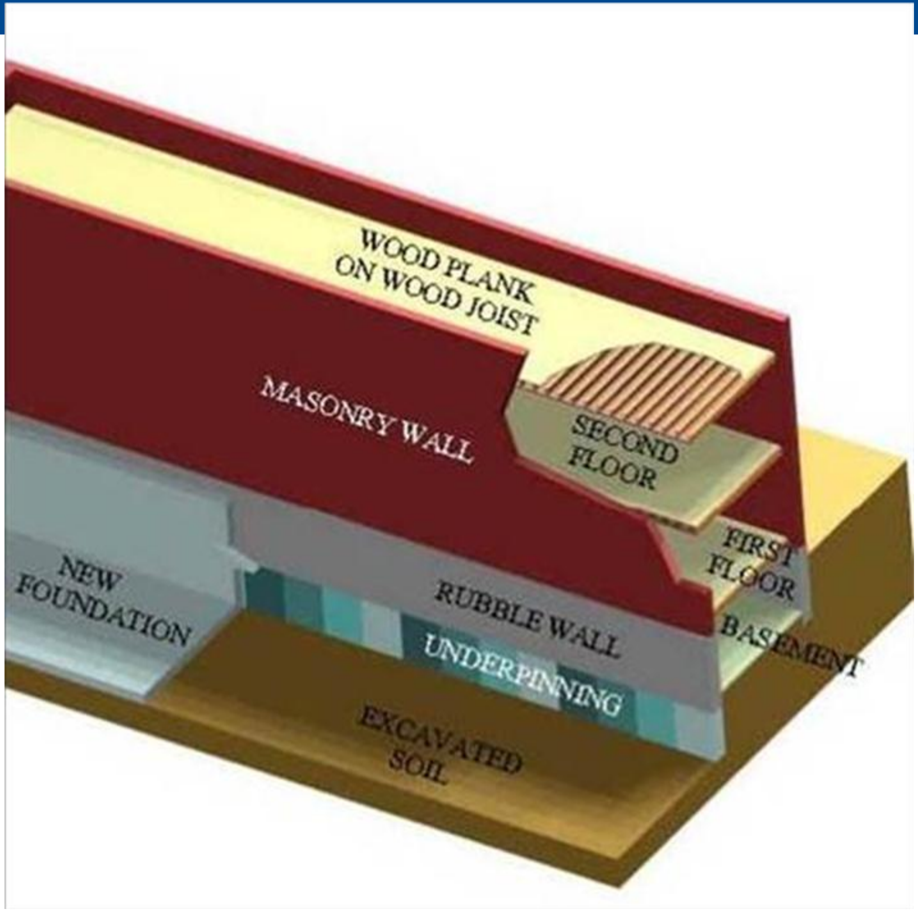


Underpinning as support of excavation

The “repeated one pin” approach might misses considering the larger effect on the entire wall or building produced by the installation of a “support of excavation” system.

The sketch shows clearly that at some point in the execution process a support of excavation system is in place.

Lateral loads exerted on this support system will induce forces in the existing building wall above and in the foundation bellow.



Steps for designing a pin underpining

A. Determine soil bearing capacity and other properties.

B. Existing Building (to be underpinned)

  a) Determine condition of existing building

  b) Determine potential response of existing building

C. Determine vertical loads on existing foundation

D. Evaluate dimension of pin (for each phase).

E. Determine the structural model of the underpinned structure that satisfies the known building and soil conditions.

F. Verify strength, sliding and overturning for each element at each phase, including soil carrying capacity.

A. Soil properties and capacity

From probes and soil report determine soil properties:

- Soil allowable bearing pressure at existing foundation level
- Soil allowable bearing pressure after removal of overburden
- Soil allowable bearing pressure at the base of pin
- Possible presence and influence of underground water
- Where tier underpinning is contemplated, soil capacity at each tier bottom needs to be determined.
- Lateral pressure exerted by soil at pin level. Note that the type of lateral pressure exerted by the soil that is used in calculations needs to be considered in conjunction with the capacity of the existing building to suffer some deformations.

Active vs At Rest Soil Pressure

- One needs to be aware that the active soil pressure is a lower boundary of the soil lateral pressure (that is, higher lateral pressures might develop). These values can be used assuming that some rotation or displacement may take place (that is, the wall system has some flexibility)
- In some particular cases, some minor rotation or displacement might be accommodated (elastically?) by the building/foundation/pin system. These minor movements could be sufficient to lower the lateral pressure to active pressure values.
- When the system is fragile and/or no movement is acceptable, the calculations need to use <u>at rest pressure</u>. For instance rubble walls, especially those in poor conditions, should be considered having no flexibility.

B. Existing Buildings

NYC Buildings

The structural configuration of the building to be underpinned plays an essential role in the design of the underpinning.

The majority of the underpinning problems occur during underpinning of load bearing unreinforced masonry buildings. These older buildings have never been explicitly designed to sustain horizontal loads. When horizontal (lateral) loads are applied perpendicular to the face of a masonry wall (out of plane loads), the wall's response is weak. Pin underpinning has the potential to introduce such out of plane loads.

Understanding the potential response of the underpinned building to lateral load is now a specific code requirement.

Condition Assessment of Existing Buildings

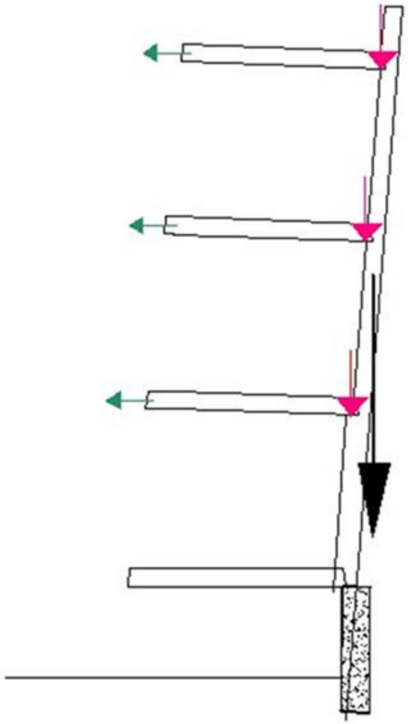
- Building lean
- Wall cracks
- Wood deterioration
- Evidence of foundation settlement
- Eroded mortar joints

Vertical cracks at corner

- Cracks at corner indicate serious problems with general building stability and load paths to shear walls.
- Some corner ties installations are not always effective.

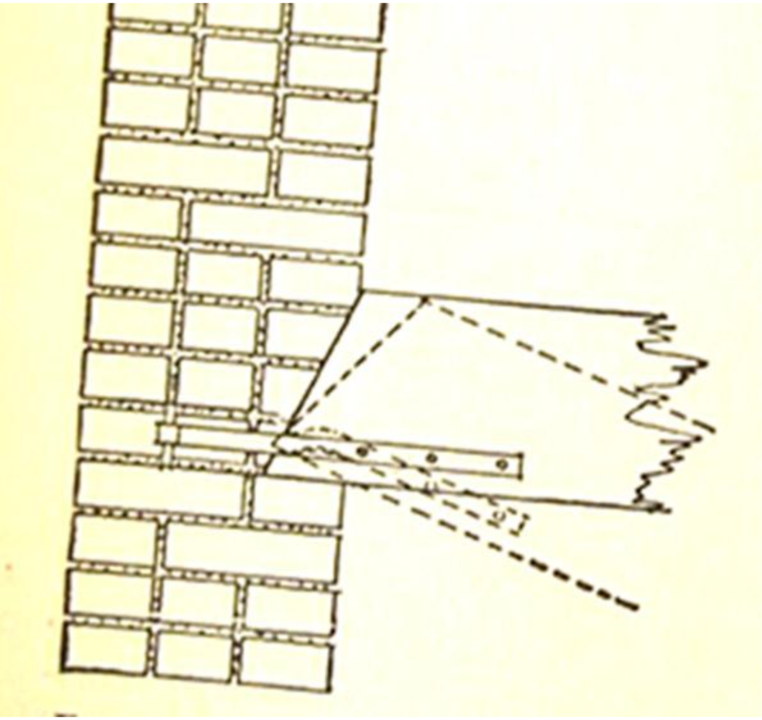
Wall leaning outward

- The weight of the wall itself increases the walls' tendency of the rotate. The capacity of the load path to transfer to shear walls the forces induced by the lean may be at its limit.
- One of the probable causes of the lean is poor condition of foundation. This will be further destabilized by underpinning.
- The lean of the building can increase and reach collapse even under only service loads.

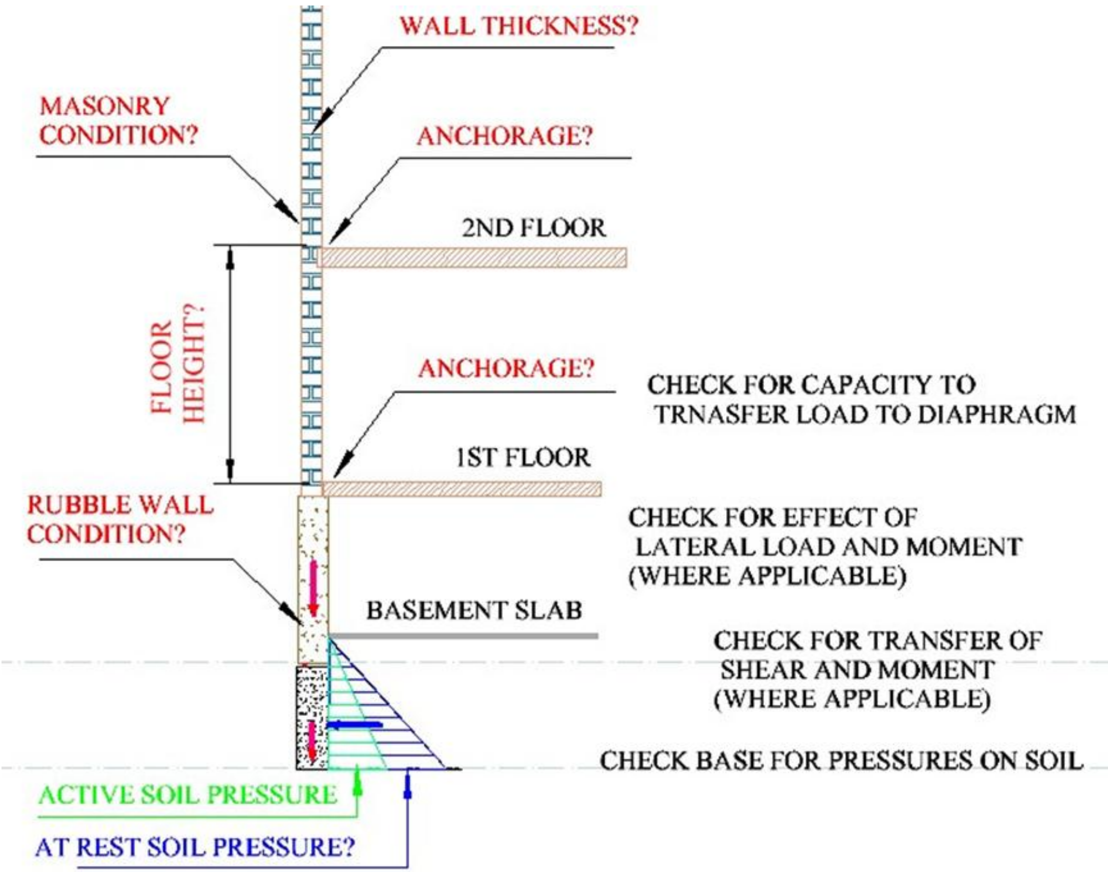


Elements Influencing Stability and Load Path

- Floor to floor height vs. wall thickness
- Floor and joists anchorage to walls
- Wall to wall anchorage
- Interior walls
- Number of floors



Existing building



Soil Lateral Pressure

DESCRIPTION OF BACKFILL MATERIAL[c]	UNIFIED SOIL CLASSIFICATION	DESIGN LATERAL SOIL LOAD[a] (pound per square foot per foot of depth)	
		Active pressure	At-rest pressure
Well-graded, clean gravels; gravel-sand mixes	GW	30	60
Poorly graded clean gravels; gravel-sand mixes	GP	30	60
Silty gravels, poorly graded gravel-sand mixes	GM	40	60
Clayey gravels, poorly graded gravel-and-clay mixes	GC	45	60
Well-graded, clean sands; gravelly sand mixes	SW	30	60
Poorly graded clean sands; sand-gravel mixes	SP	30	60
Silty sands, poorly graded sand-silt mixes	SM	45	60
Sand-silt clay mix with plastic fines	SM-SC	45	100
Clayey sands, poorly graded sand-clay mixes	SC	60	100
Inorganic silts and clayey silts	ML	45	100
Mixture of inorganic silt and clay	ML-CL	60	100
Inorganic clays of low to medium plasticity	CL	60	100
Organic silts and silt clays, low plasticity	OL	Note b	Note b
Inorganic clayey silts, elastic silts	MH	Note b	Note b
Inorganic clays of high plasticity	CH	Note b	Note b
Organic clays and silty clays	OH	Note b	Note b

1814.1.1 Underpinning and bracing.

NYC Buildings

2014 Code

Underpinning piers, walls, piles and footings shall be designed as permanent structural elements and installed in accordance with provisions of this chapter and Chapter 33 and shall be inspected in accordance with the provisions of Chapter 17. Underpinning shall be designed and installed in such manner so as to limit the lateral and vertical displacement of the adjacent structure to permissible values as established in accordance with Section 1814.3. The sequence of installation and the requirements for sheeting, preloading, wedging with steel wedges, jacking or dry packing shall be identified in the design.

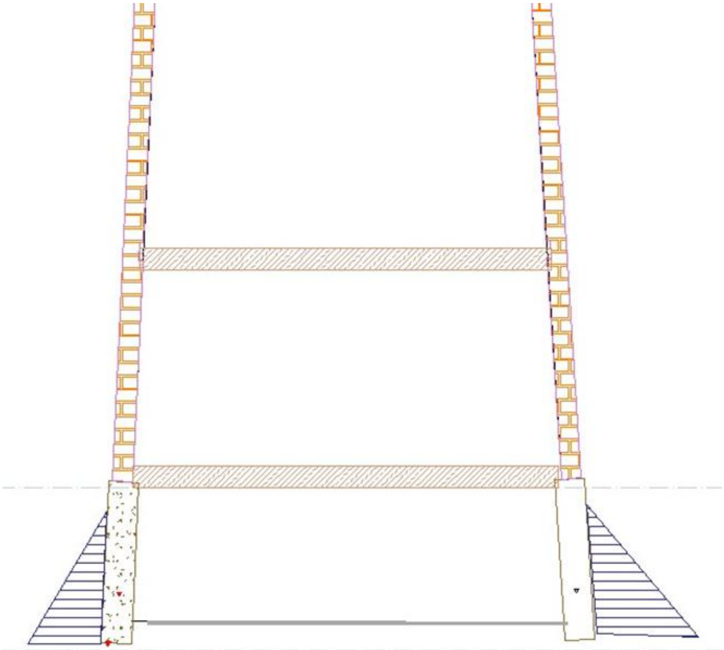
1814.1.1 Underpinning and bracing

(cntd)

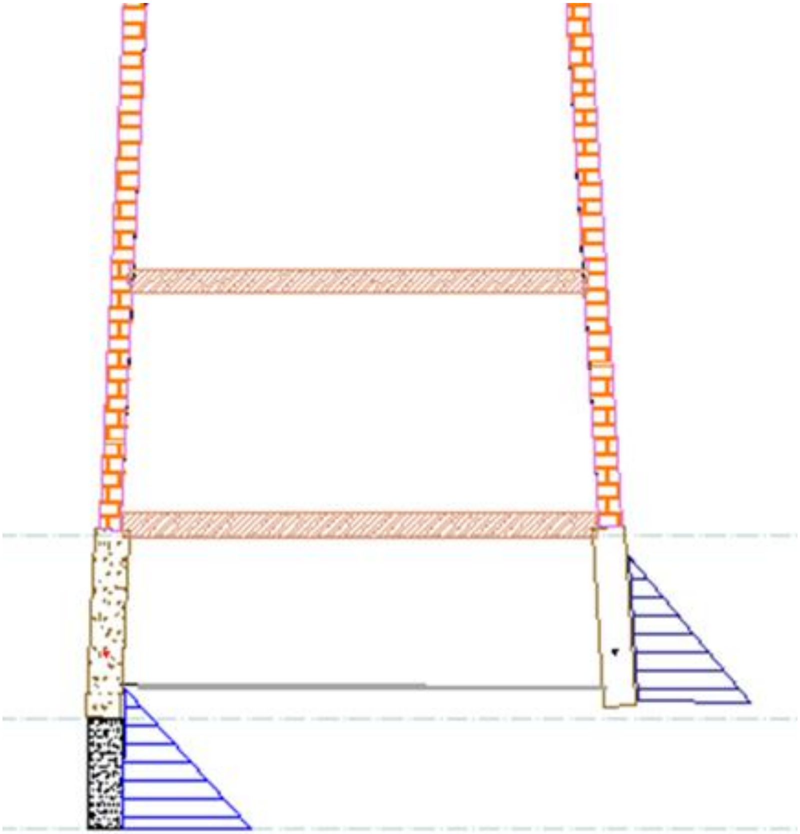
The design shall take in account the <u>effects on foundation and structure produced by the lateral earth pressure exerted on the underpinning.</u> Lateral support for underpinning, if needed, shall be accounted for during the design of the new construction. The design and construction sequence of temporary lateral supports used prior to the installation of the foundation walls shall be included on the design drawings.

Change in forces and stresses?

The original intent of some better masonry builders was to keep the floor diaphragm in compression. Soil pressure on foundation walls as well some inclination of the foundation bottom contributed to this. When in compression, the capacity of the wall to joist tie is less important.



Underpinning might change the general distribution of forces. The lateral soil pressures might not balance. In the new condition the capacity of the diaphragm to wall connection becomes important. It is essential to prevent the raking of the building.



C. Determine vertical loads

- There is only slight difference between present code and older codes in terms of live and dead load.
- Determine pressure at base of brick
- Determine pressure at base of rubble wall foundation in existing condition.
- Account for eccentric loads (especially due to building leans).

D. Evaluate pin dimensions

- The pin dimensions are governed by the capacity of the foundation above to span (in undisturbed condition).
- The number of simultaneous pin instillations shall consider the need to keep within allowable values the pressure on underlying soil. (at each step of the sequenced operation).
- The capacity to operate safely from the approach pit.
- The size of the pin is many times limited by site/shape new building considerations. (Is this acceptable?)

Compute length od pin dug simultaneously in one phase.

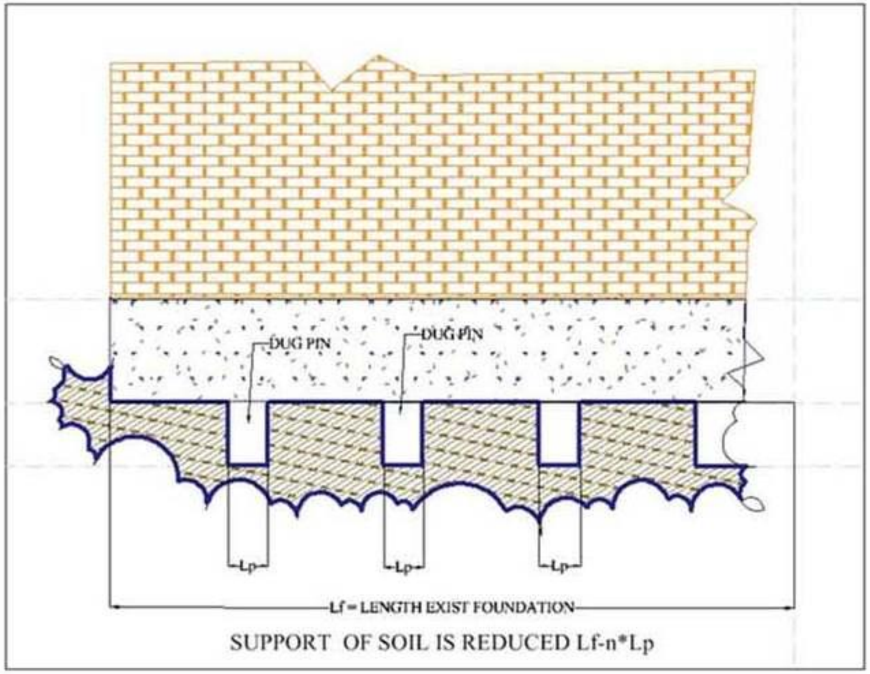
- Phase 1. After digging to install pin the area of soil supporting foundation is reduced.
- Original pressure

$$\frac{W}{\text{Area foundation}}$$

- At end of phase 1 pressure is

$$\frac{W}{(Lf-n*Lp)*B}$$

For a 4 pit sequence the vertical pressure is increased by 33% ???



B - thickness of foundation.

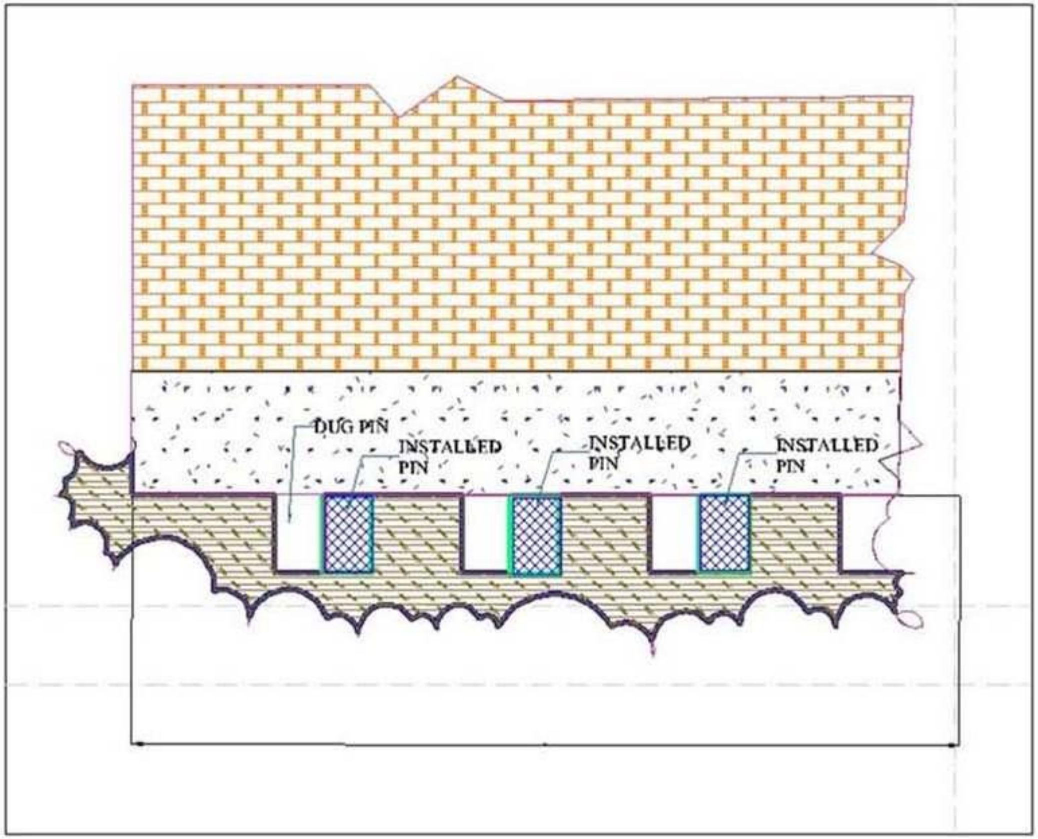
Lf – length foundation

n – number pits

Lp – width of pit

Compute Width/Length of Pin

Phase 2. After first pins are installed and the digging for the next sets of pins – the pressures at the base of first pins will be increased by the effect of soil lateral pressure and possible eccentric shimming (OR LACK OF).



Pressure of base of first pins

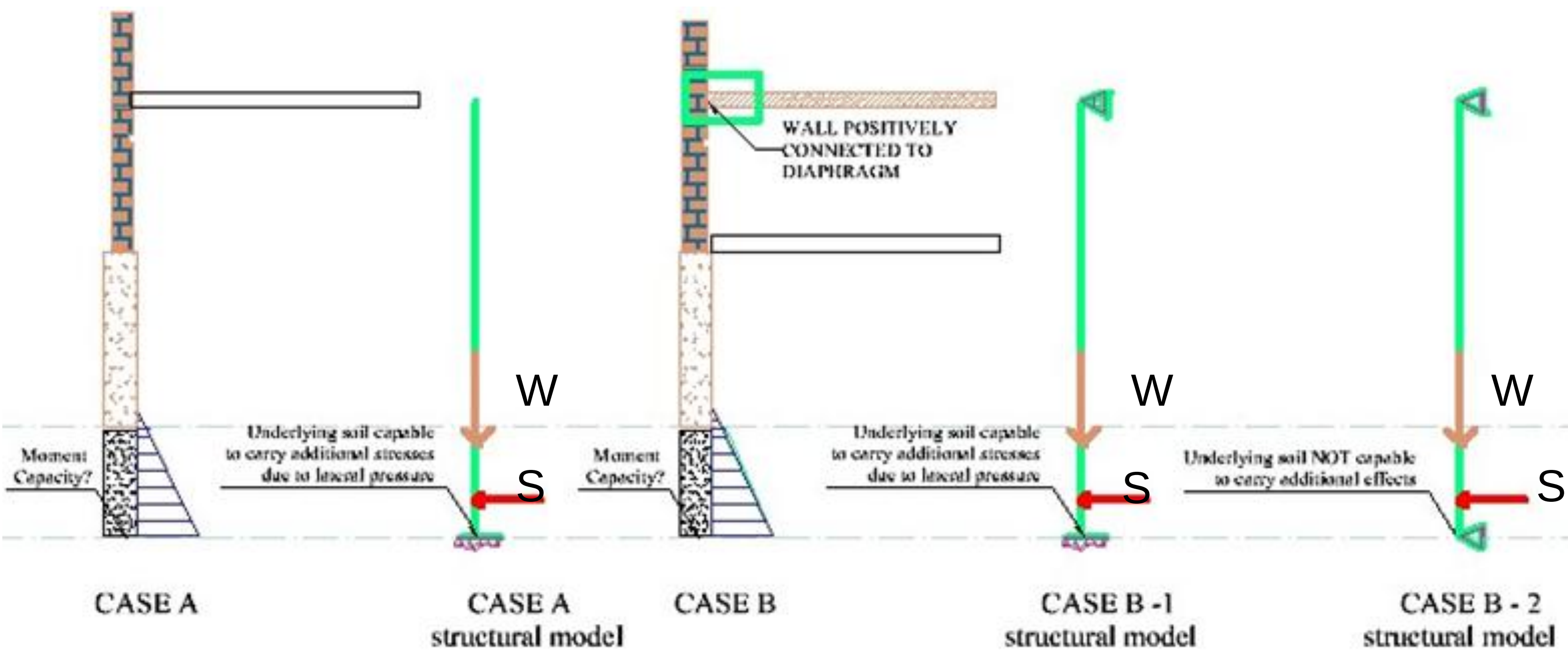
$$\frac{W}{(\text{Area foundation} - \text{Area pin 2})} + \frac{\text{M lateral forces p}}{\text{S pin1}}$$

E. MODELLING THE UNDERPINNED STRUCTURE

- The designer needs to determine a structural model that satisfies the soil bearing capacity and the capacity of the existing structure to carry the newly imposed loads.
- If for whatever reason (e.g. lack of access, lack of probes, etc.) a condition is not positively known, **the most detrimental case should be considered.**
- If the existing structure is not capable to carry newly imposed loads, these loads shall be carried by special installations (e.g. anchors, braces) or **solutions other than pin underpinning need to be considered**.

E. MODELLING THE UNDERPINNED STRUCTURE

IN ALL CASES THE SOIL SHALL BE ABLE TO SAFELY CARRY THE APPLIED VERTICAL LOAD W



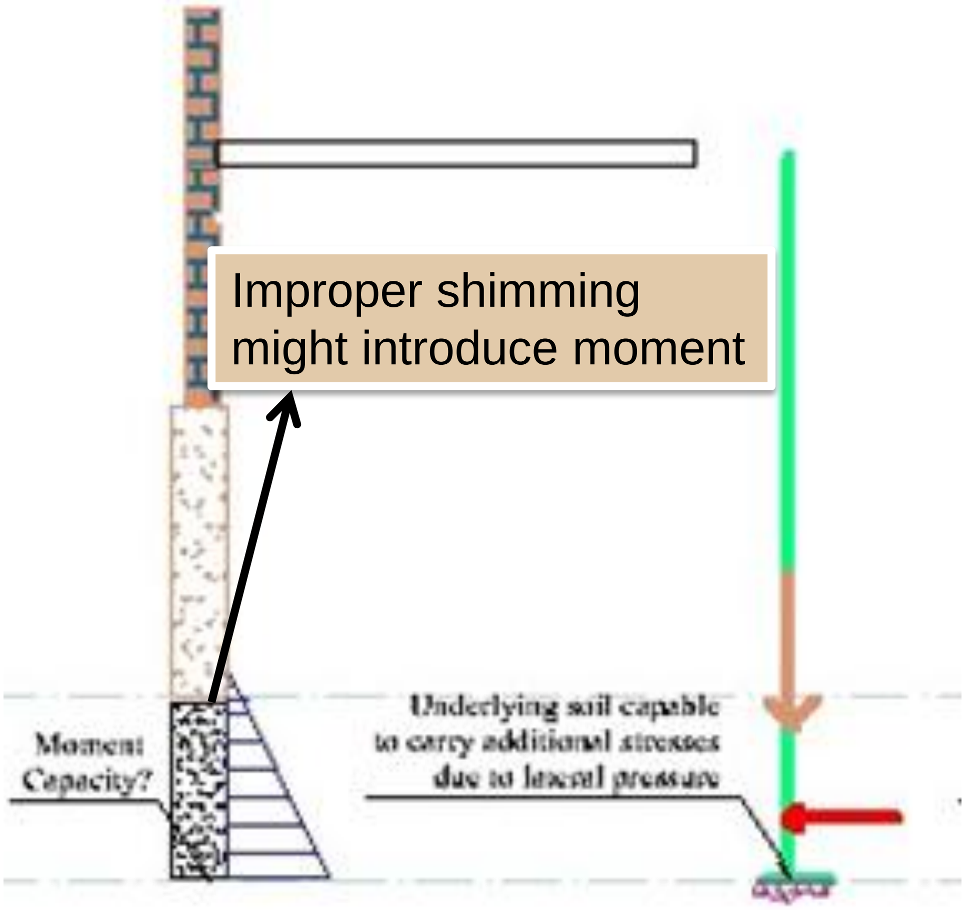
STRUCTURE DOES NOT PARTICIPATE IN RESISITING FORCE “S “

WITHOUT SUPPORT FROM THE BUILDING THE EFFECTS OF FORCE “S” OVERWHELM SOIL CAPACITY

CASE A

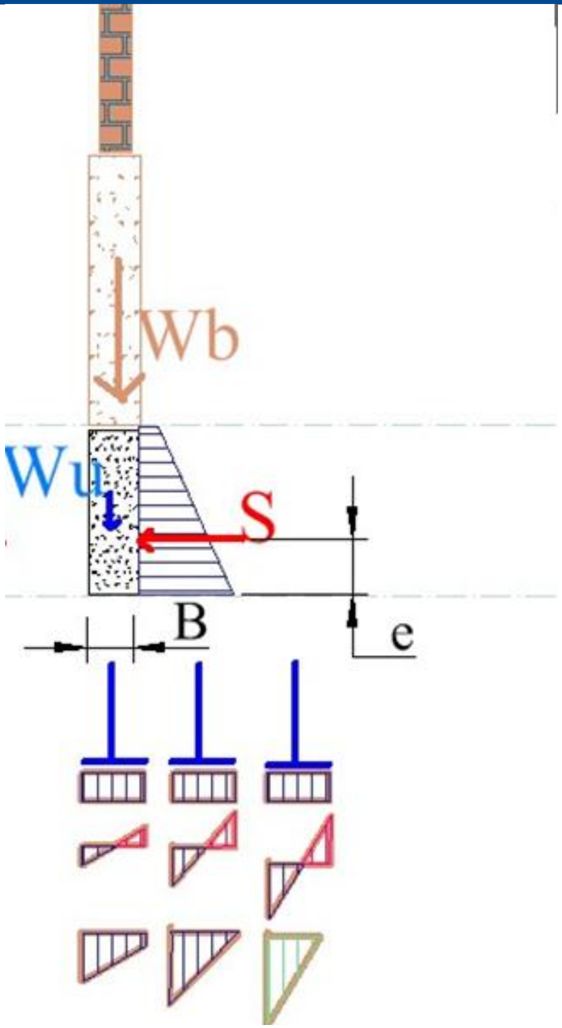
As long as the soil can safely resist all loads and the system pin & wall do not overturn, the lateral loads transmitted to the building are minimal as the system could work as a retaining wall (without top support.)

No lateral support provided by the building



CASE A

- The entire effect of soil lateral pressure is taken by base of underpin.
- The building on top does not support any portion of the soil lateral load
- It acts as a cantilever, restrained at the base (or as retaining wall.)
- Depending on the size of the various loads and geometry one of the three possible pressure on soil conditions might occur

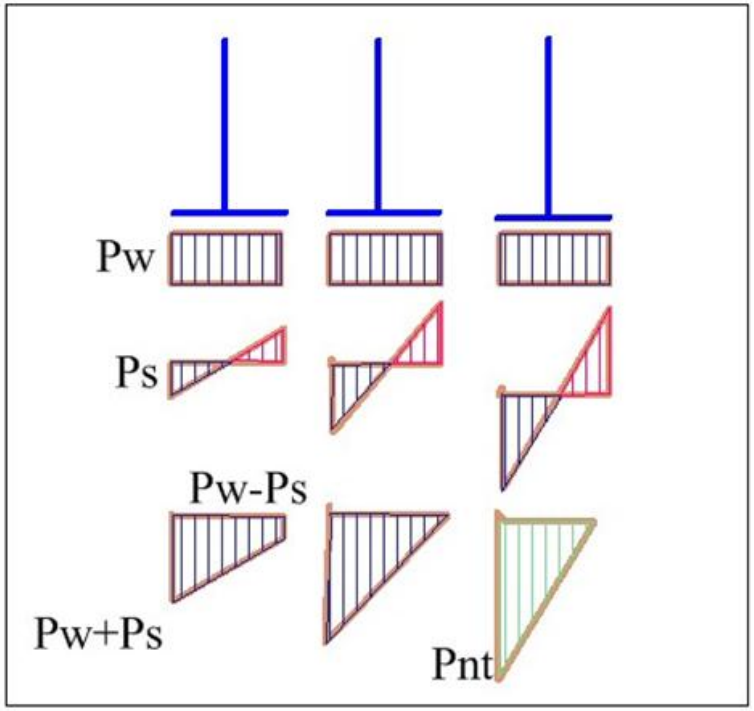


CASE A.

The pressure exerted by the pin base on the soil is the resultant of the combination of vertical forces and moment due to the soil lateral pressure.

A special case is when the calculated tensile stresses are larger than the compression due to the vertical forces (see model calculation) .

When Pnt exceeds soil bearing values CASE A model cannot be used.



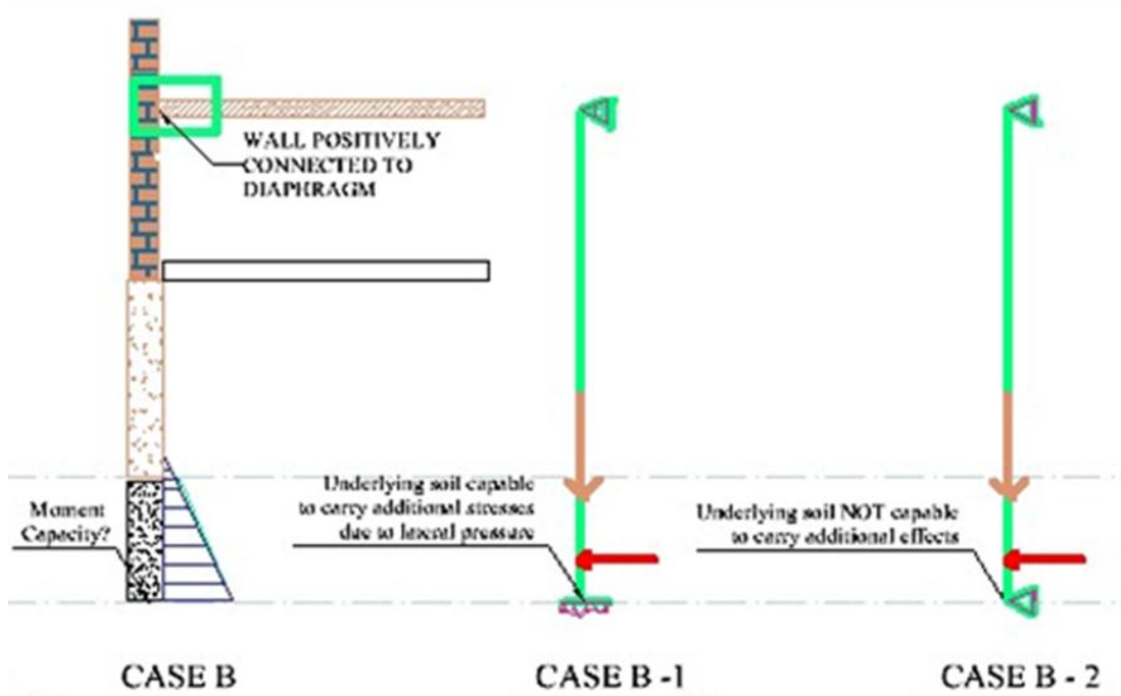
Pw -from vertical loads

Ps - from lateral soil pressure

Pnt - from combined load
no tension on soil

CASE B

The loads applied to the soil underlying the pin create an overstress condition. In the absence of additional lateral support the system will move. The floor diaphragm (or any other load resisting system) needs to absorb some loads.



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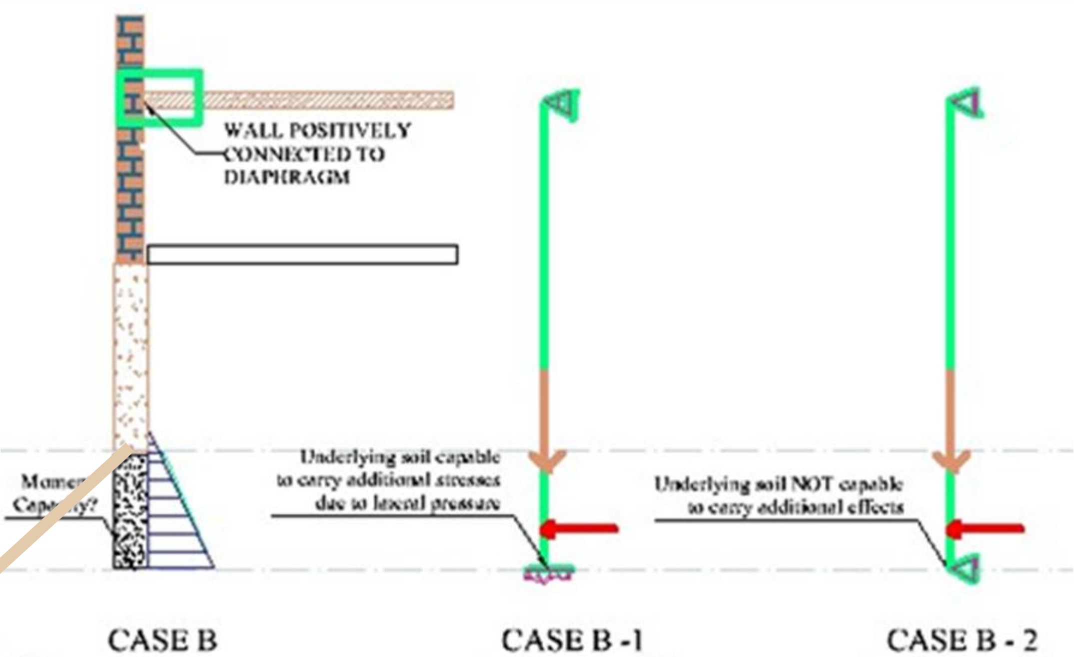


NOTE – one needs to verify the interface – pin/existing foundation for moment transmission

CASE B

CASE B-1

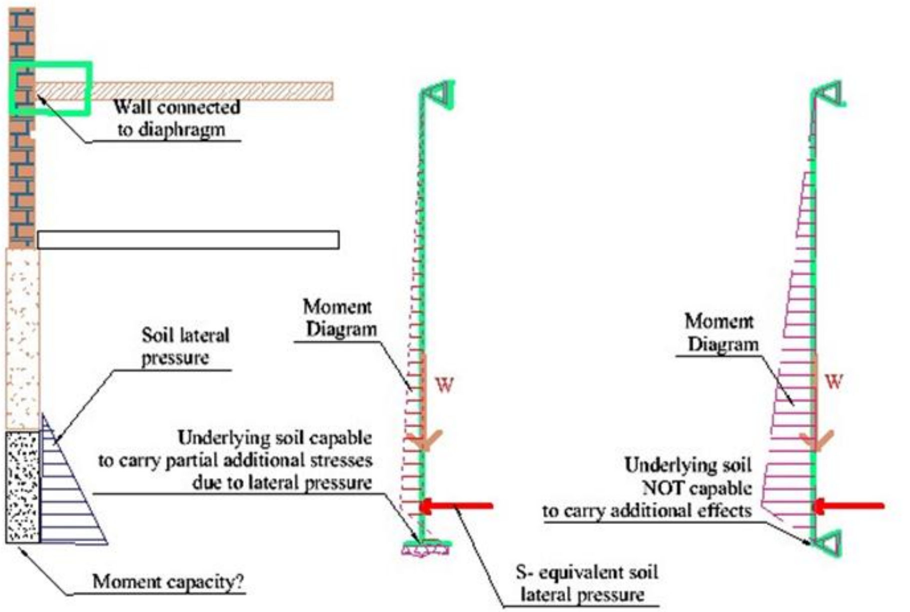
In the loads transmitted to the diaphragm are those that limit the stresses at the base of the underpin to within safe values.

CASE B-2

In the soil does not have reserve of bearing capacity and no moment restraint is present. The model a simply supported beam/column.

CASE B

- The anchorage wall – diaphragm needs to be capable of receiving and transferring the loads.
- Each element in the load path needs to be verified for stresses and limit of movement.
- The ensemble wall + foundation + pin form a column that needs to be verified.



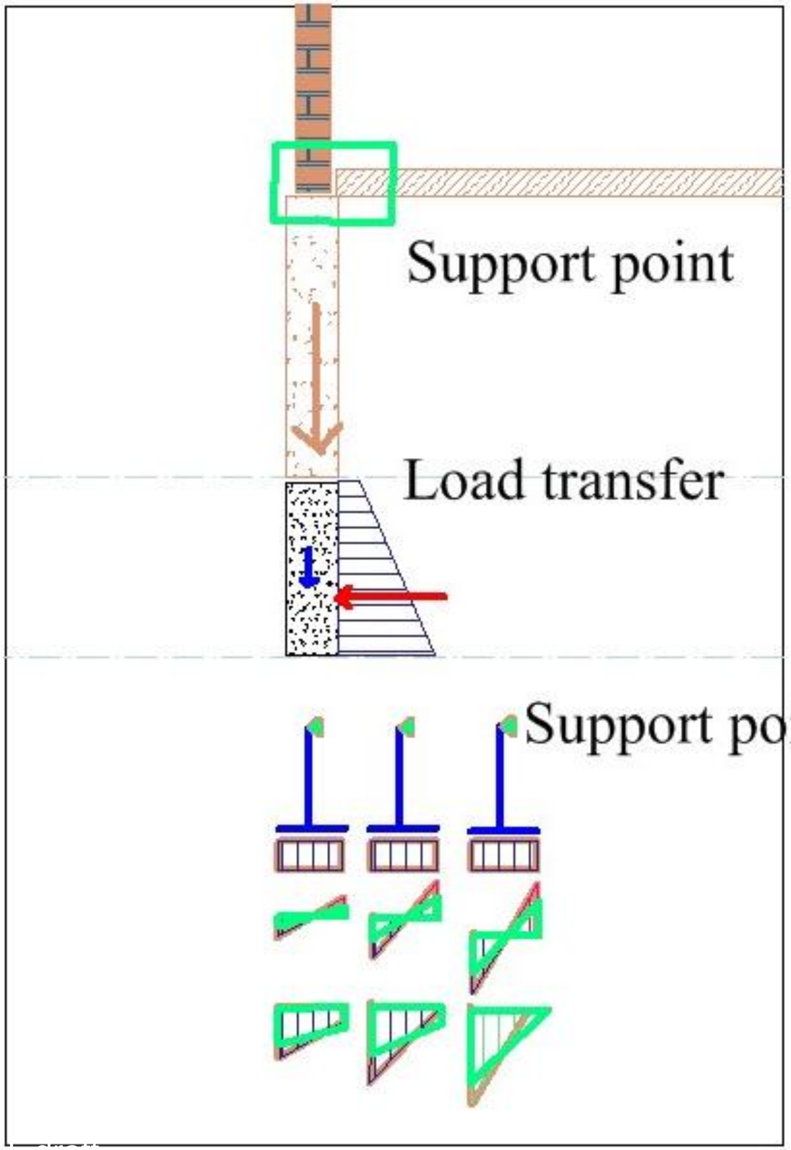
CASE B -1 model
Underlying soil capable to carry partial additional stresses due to lateral pressure

CASE B - 2 model
Underlying soil NOT capable to carry stresses beyond those produced by building weight

Floor support

When the system is capable of transferring out of wall plane loads to the diaphragm (or other system), the stresses exerted on the soil at the base of pin are reduced.

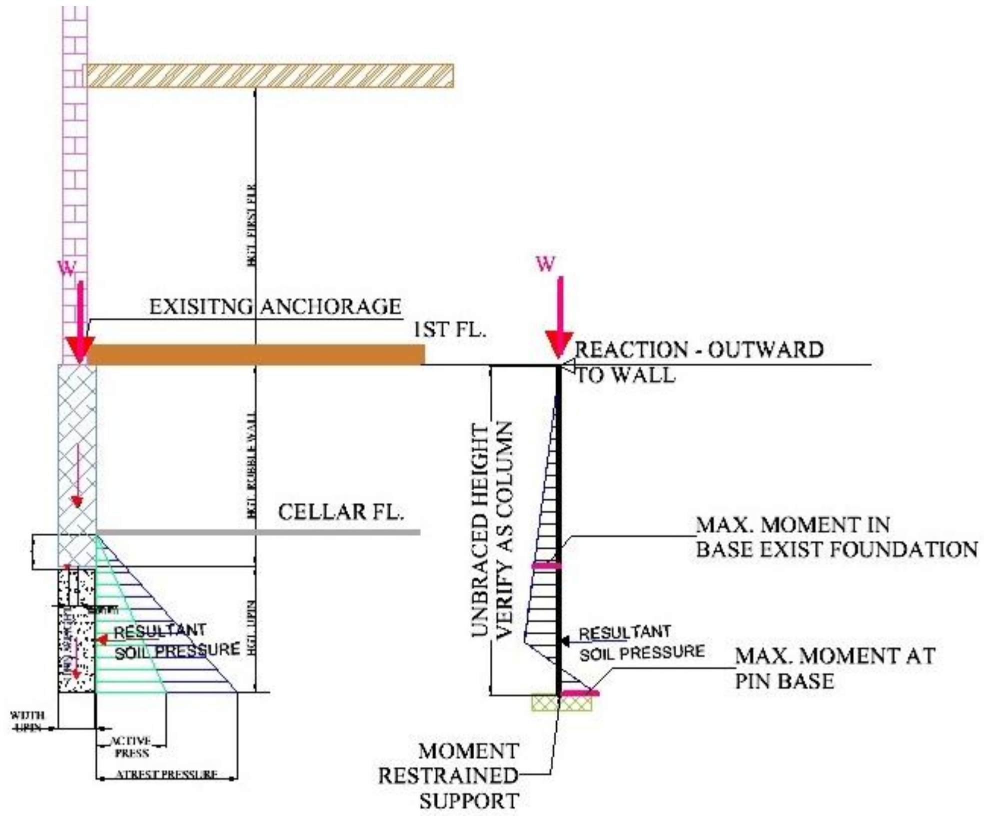
For all cases, the system brick masonry, rubble foundation and underpin needs to be verified as a column under vertical and lateral forces. The height of the column shall be considered from the soil to the first wall diaphragm connection.



CASE B-1
U/P DIAPHRAGM ANCHORED AT 1ST FLOOR

Anchorage at 1st floor is rare.

In some cases friction between the first floor and foundation might provide some support.

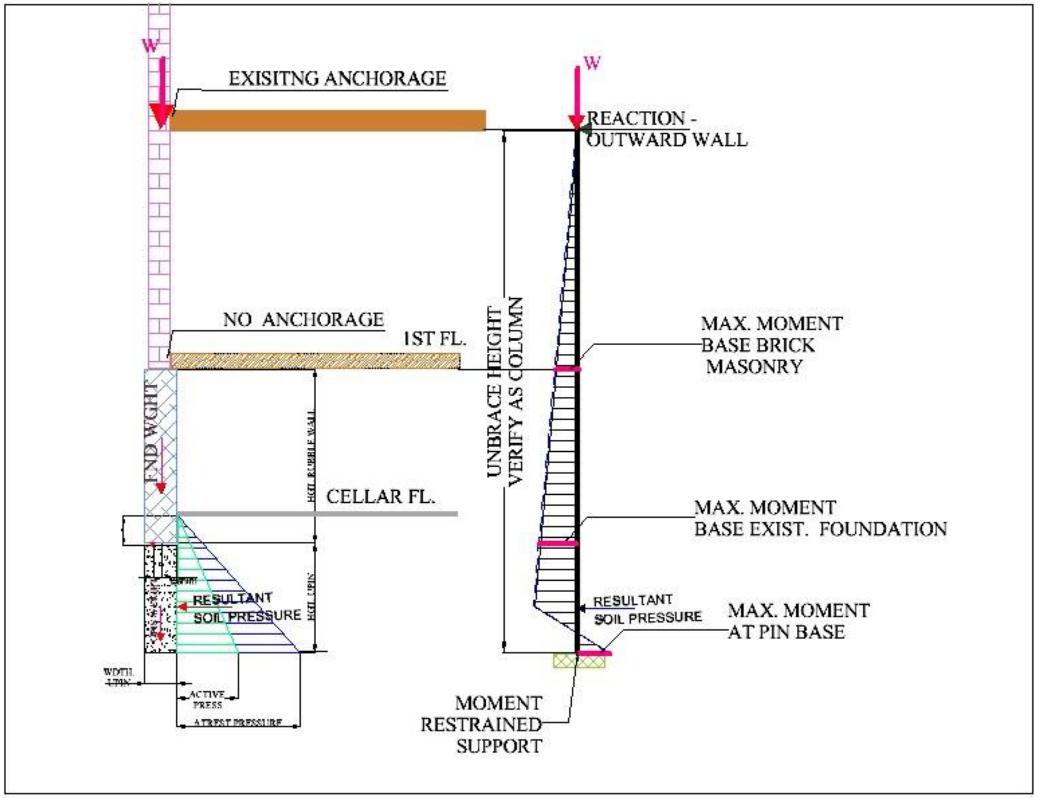


CASE B-1 U/P DIAPHRAGM ANCHORED 2ND FLOOR

Usually the wood floor (soft diaphragm) has some anchorage at the second floor.

One needs to consider that the joists embedded in masonry pockets might be rotted.

For calculations of unbraced length and corresponding ratios one needs to consider the thickness of each component material.



MSJC Slenderness Ratios

Type	Max l/t or h/t
Bearing Wall	**20**
Solid or Grouted	**18**
Exterior Non Bearing	**18**
Interior Non Bearing	**36**

t= masonry thickness

h= unsupported height

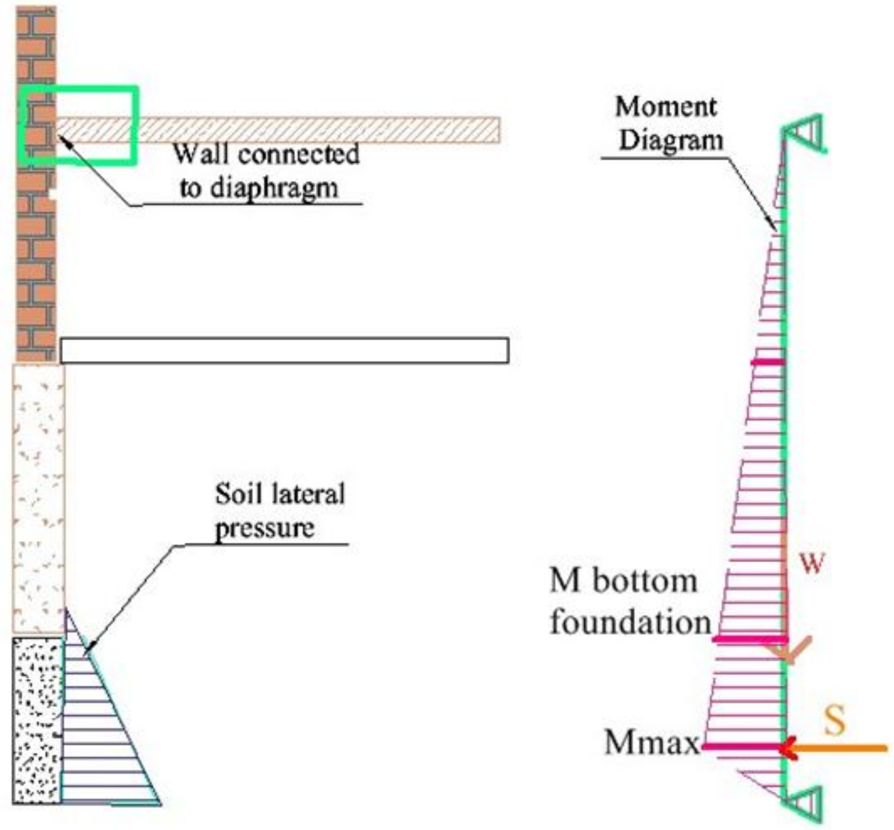
l= horizontal distance transverse walls

MSJC – Empirical Design

Note that following the example of the MSJC (TMS 402/ACI 530/ASCE 5), the empirical design of masonry is becoming severely limited.

Case B-2

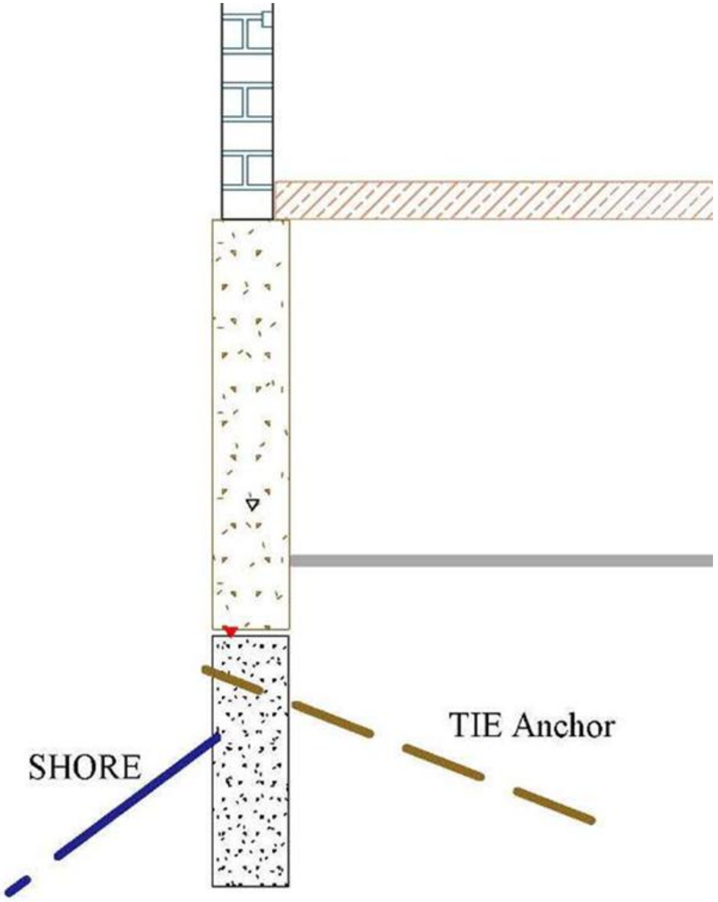
- The soil underlying the underpin can carry only vertical loads. The base is acting as a pinned support. Similarly the attachment to existing structure.
- This model brings the largest loads to the structure and largest moments in the pin/foundation/pin structure. This structure acts as a column subjected to moments.



Provide Support!

When you cannot ascertain capacity of structure to carry lateral load

PROVIDE SUPPORT!



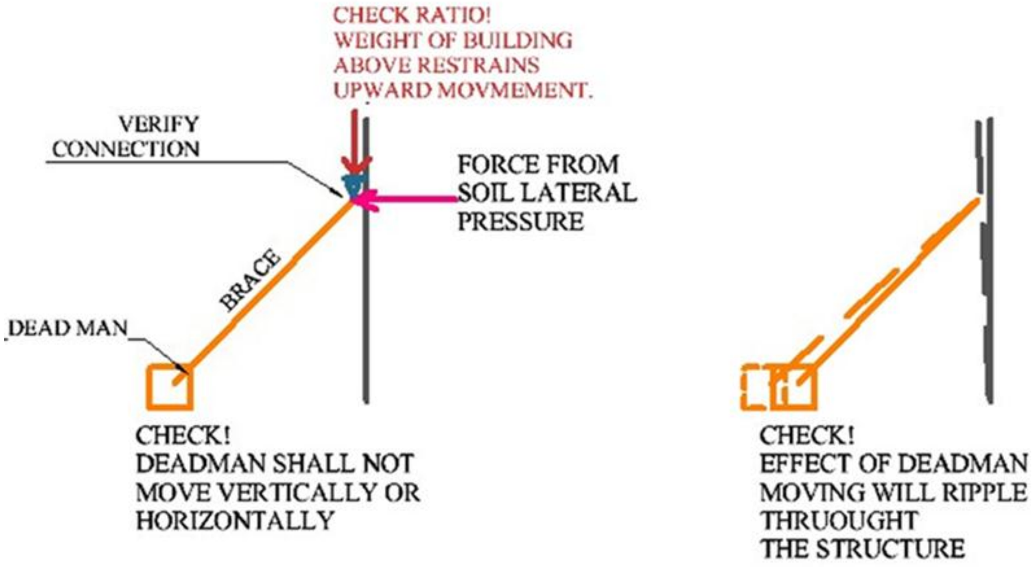
BRACE AND DEADMAN ISSUES

Dead man needs to be sized to avoid any movement

Placement of deadman needs to take in account further excavations.

The deadman also needs to be checked for overturn.

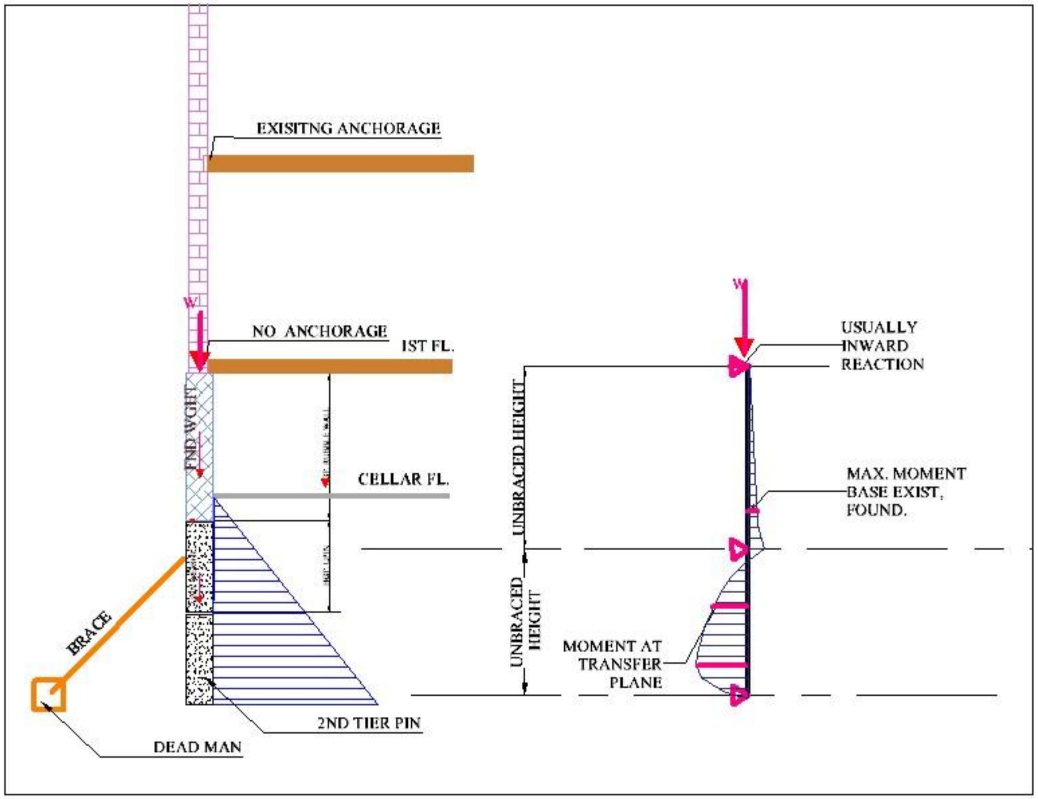
Connection pin-brace needs to be capable to transfer vertical force.



2 TIER U/P
BRACE @ TOP PIN

System prevents transfer of significant out of plane forces to existing masonry (brick and rubble wall).

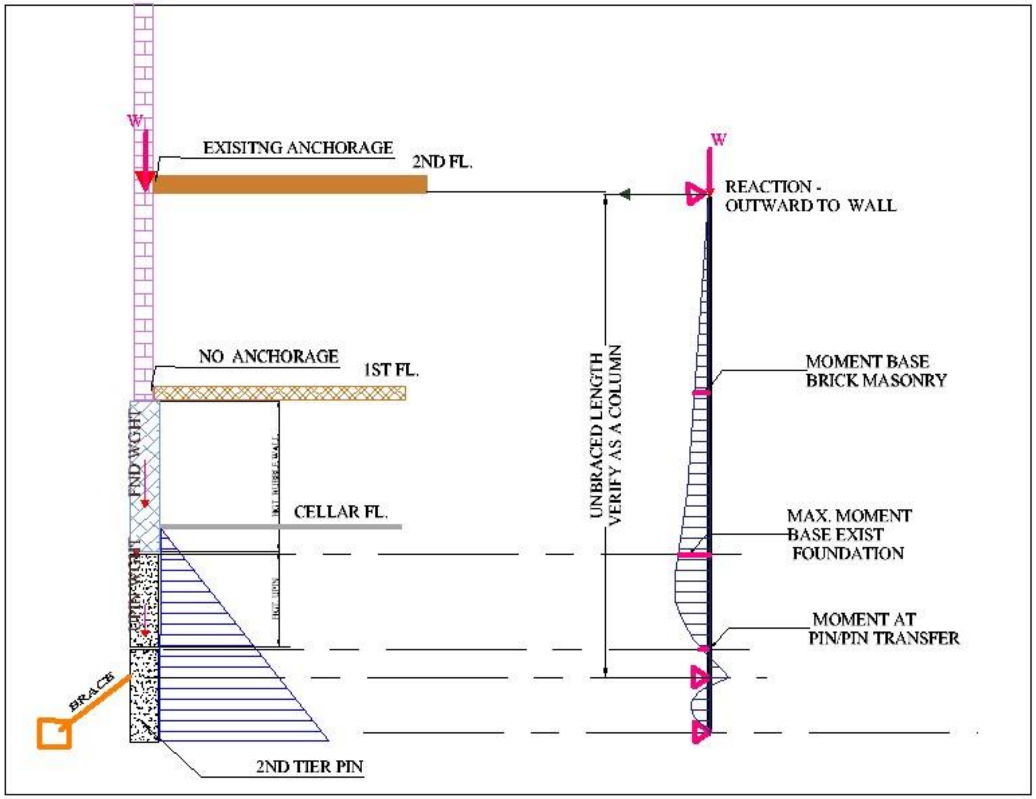
The difficulty of this installation is finding a place for the deadman that will not be disturbed by subsequent excavations. The deadman needs to be installed prior to digging for the second tier pins.



BRACE 2ND TIER PIN

Bracing of the second tier pin will introduce out of plane outward loads on the existing wall

The unbraced length of the wall & foundation & pin is the largest of all the schemes. Similarly the shear at the pin interface is larger.



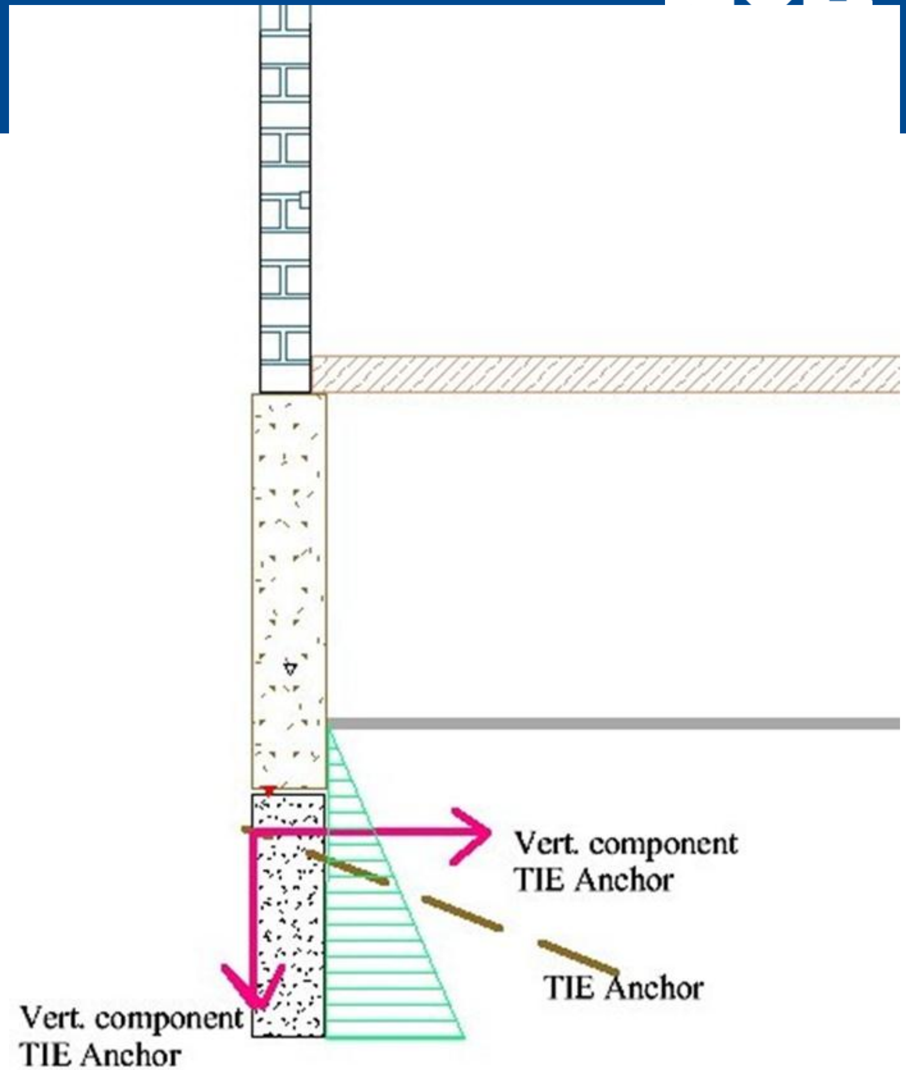
In many cases this scheme introduces a large moment at the base of the existing foundation (but probably less demanding as this foundation now is now supported by a pin)

Tie Anchors

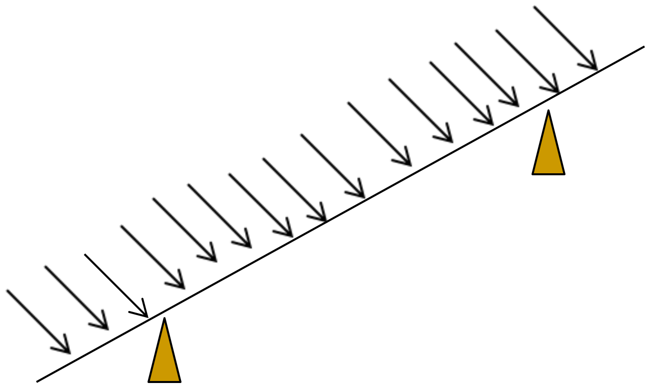
The installation of a tie anchor introduces loads that need to be considered in detail.

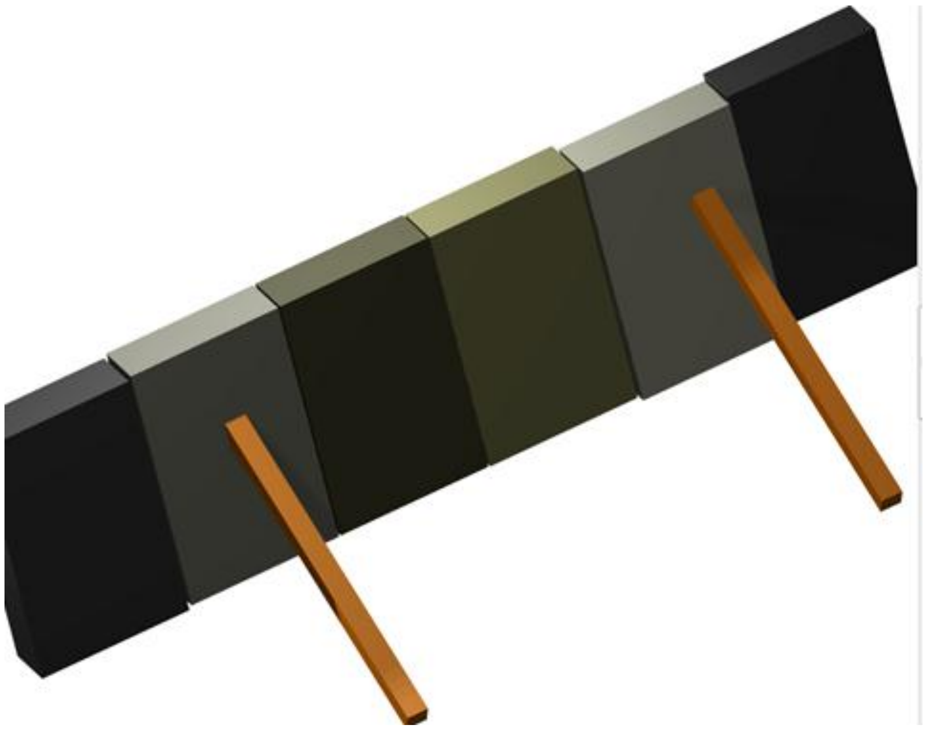
The vertical load can be substantial and will increase the pressure on the soil. Also it might weaken any shimming (already installed).

The horizontal loads shall not negatively influence the base of the existing foundation



Transfer lateral pressure to support points





The lateral forces exerted on the pins that are not supported, need to be transferred to the brace (or anchor) via reinforcing and /or shear keys.

1704.20.1.1 Construction operations influencing adjacent structures.

2014 Code

Where construction operations have the potential to affect structurally the condition or occupancy of the subject structure and/or an adjacent structure, the structural stability of the such structures shall be subject to special inspections in accordance with Sections 1704.20.6 through 1704.20.10.

1704.20.7.1 Monitoring.

2014 Code

The design documents shall include any requirements for monitoring of the subject structure and/or adjacent structures, as determined by the registered design professional responsible for the design. The monitoring plan shall be specific to the buildings to be monitored and operations to be undertaken, and shall specify the scope and frequency of monitoring, acceptable tolerances, and reporting criteria for when tolerances are exceeded.

Specific to the building

- Inspect building
- Determine condition
- Determine weak elements
- Potential of distress due to movement or vibration

Protocol of Actions

- The monitoring program shall include necessary actions to address exceedence of pre-established thresholds..
- Whom to communicate
- Adjust construction ops
- Reevaluate construction ops

Conclusions

a) The engineer needs to understand the building being underpinned.

b) There should be calculations for every step of the underpinning operations.

c) The 2014 code provides more specific requirements

- It requires all designs and monitoring to be specific to the buildings being underpinned
- It requires an analysis of the existing building for the lateral forces developed during the underpinning