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Earthquake

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CONTENTS

CHAPTER ONE: INTRODUCTION:

1.1 earthquakes

The earth quick is defined as a releasing of energy is built up by stresses in the rocks of crust considering geological faults or by movement of magma in volcanic area (Duggal, 2007) . At this stage, seismic waves are generated. The earthquake is a global phenomenon by this the earth was formed billion years ago. This generates by seismic waves in rock layers of earth crust which is known as tectonic plates. Faults and discontinuity in the earth crust make movement in the tectonic plate and then the movement turns to vibration and oscillation (Khan, 2013).

The buildings response is essential in terms of absorbing motions that result in the ground acceleration by building's ductility behaviour and stiffness. Both superstructure and substructure should be well-designed according to conceptual principles of construction structure according to degree of vulnerability. Foundation must be designed to resist strong vibration with resonance phenomenon between foundation and ground. Superstructure (frame of building) must be designed to reduce the lateral displacement due to inertia force regarding to mass of structure. This can be avoided with increasing stiffness of vertical ties. The effects of earthquake on building principally depend on three time histories parameters which are ground acceleration, velocity of motion and displacement (Bachmann, 2003).

1.2 Causes of Earthquake:

(Duggal, 2007) states the different causes of earthquake which are

1- tectonic (relative movement of plates)
2- plutonic (deep seated changes)
3- volcanic (on the basis of the source stress that cause movements)

1.3 Consequences of earthquake**:**

1- ***Loss of life***
2- Earthquake can be classified as a major natural disaster for people life in the xase of death and immigration**.**
3- ***Environment***
   The catastrophic earthquake may lead to destroy environment by polluting weather
4- ***Socio-economic declination :***
   The destructive earth quake may lead to collapsing many structural such as buildings, bridge and dams. These infrastructure failures impact on the economic growth

1.4 how to control damage of structures

Engineering earthquake deals with meeting performance level of building resistance to earthquake. Codes and practices has been established to consider the buildings vulnerability with earthquake. Euro code 8 set out basic principle for conceptual design under section 4.2 EN BS 1998-1-1 which are :
1- Structural simplicity
2- Uniformity, symmetry and redundancy
3. Bi-directional resistance and stiffness
4- Torsional resistance and stiffness
5- Diaphragmatic behaviour at storey level
6 - Adequate foundation

All building structures form must comply this six conceptual design to verify its performance and strength for building during earthquake.

The construction form of this two storey low rise building may be concrete, steel, timber or composite between these materials. The irregular building is modelled to be design in the different construction form. The reason behind arguing irregular building in the plan and elevation is to demonstrate the weak points in that building and achieve this building.

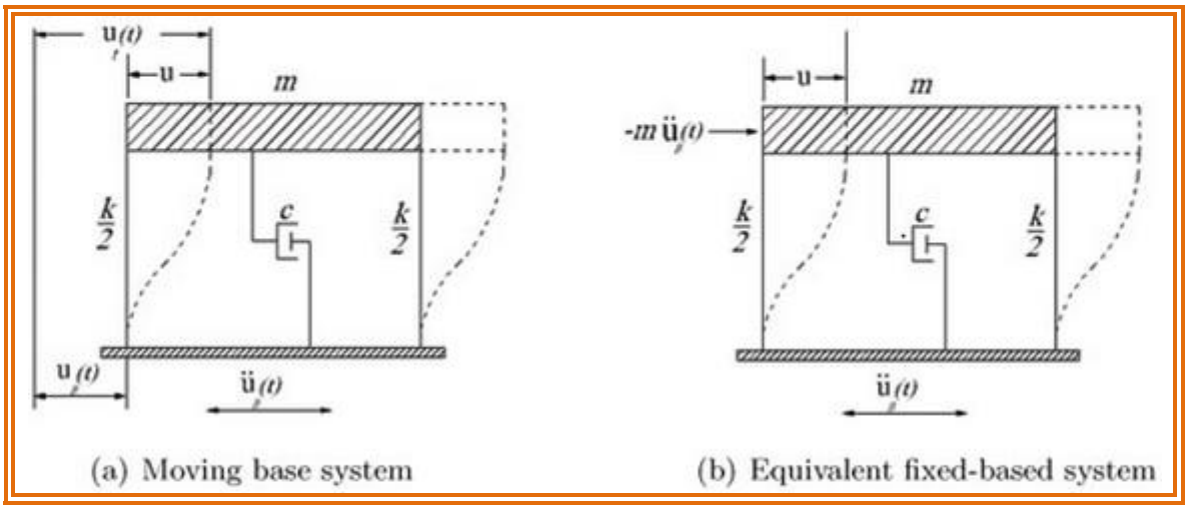
Material are proposed to be used in low rises building are based on properties such as (high ductility, high strength/weight ratio, homogeneity, orthotropic and ease to make full strength connections) (Dowrick, 1977).

1- Concrete (in-situ or precast concrete)
2- Steel column and beam with precast hollow core flooring slab. (shear resistance frame with bracing) non-bearing walls
3- Steel column and beam with metal decking flooring slab (shear resistance frame with bracing) + non-bearing walls
4- Steel column and beam (moment resistance frame) +non-bearing walls
5- Composite column and beam with reinforced flooring slab)+non-bearing walls
6- Timber column and beam with timber flooring + non-bearing walls
7- Precast concrete frame with timber flooring slab (hybrid system) +non-bearing walls
8- Masonry bearing wall with in-situ concrete flooring.

CHAPTER TWO: EARTHQAKE LOADS, REACTIONS AND LOAD PATH

2.1 Loads act the building during earthquake

According to equation of motion $mU''+cU'+KU=mUg(t)$ the seismic force consist of the following terms based on SDOF system.



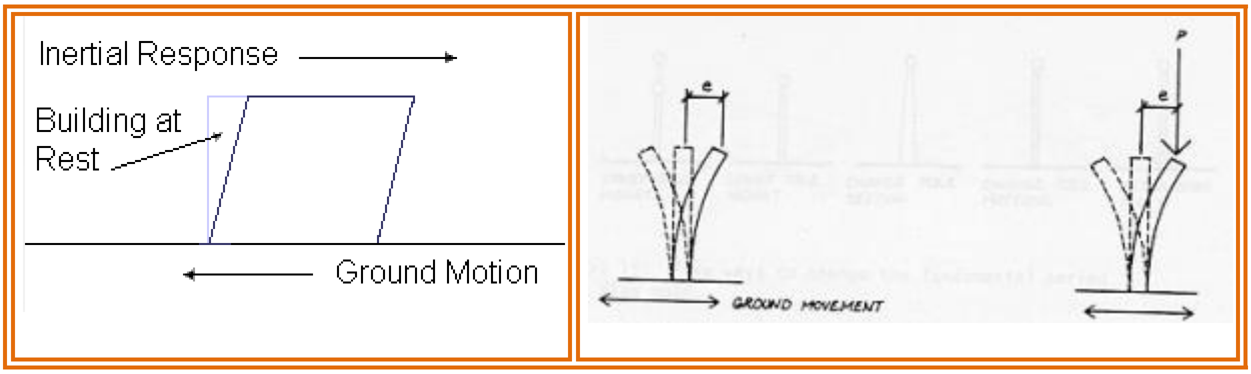
(a) Moving base system (b) Equivalent fixed-based system

fog(1) SDOF system subjected to lateral earthquake (Booth and Key, 2006)

1- **Inertia force:**

This is a first term of the equation mx'' which is tendency of building to maintain its shape from displacing it mass. This is proportional with self-weight of building as well as its configuration (Arnold and Reitherman, 1982). This force is resulted from mass and acceleration based on Newton load (F=m*a). The mass attributes of the building and acceleration is main characteristics of earthquake. There force amount of this force increase substantially with increase the mass of the building. The different of inverted elevated tank and tower demonstrate that elevated tank is more vulnerable to damage than tower because of inherent mass at the height.

The inertia force can produce the vertical load due to change of the centre of mass due to displacement then p-δ effect arises in building. Consequently, the building fails under effect of the inherent overturning moment.



fog(2) inertia force (Booth and Key, 2006, Arnold and Reitherman, 1982)

2- **Damping :**
Damping is second term of the equation of motion which is capable of returning the building to its origin position after earthquake shaking. Damping force depends on natural frequency of the materials, connection condition and non-structural materials(Arnold and Reitherman, 1982). Buildings possess some intrinsic damping. If this is insufficient to resist earthquake then it is necessary to add artificial damping system to absorb building's motion.

3- **Restoring force**: the third term (KU) of equation of motion depends on stiffness of vertical ties of the building to restore displacement

2.2 Reactions of the building

1- **Ductility**
capacity: it can be described as an ability of materials to resist force after considerable inelastic deformations and it fails and material cannot obtain its original shape such as steel. However, concrete is brittle material it raptures during yielding at plastic hinge occurrence and restore its ductility by steel reinforcement.

2- Torsion
Torsional effect is generated by earthquake inertia force, mainly due to this inertia force act at the centre of mass of each floor and twist the building around centre of rigidity. Non-symmetrical layout of lateral resisting force system arise eccentric distance between two points. This torsional force devastates building during earthquake. Caution should be taken in building design to avoid of generation of torsional moment by well design and distribute the lateral resisting force system uniformly and provide structural simplicity.

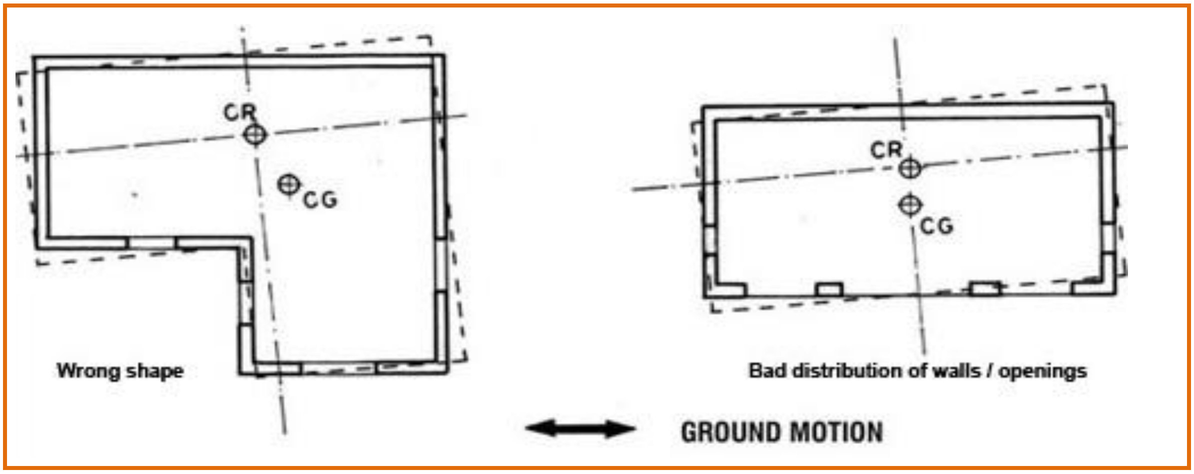


Fig (3) torsion mechanism and torsion effects (institute, 2013)

3- Base shear force

The practice has been taken into consideration in the EN-1998-1 that seismic base shear force F_b, for each horizontal direction in which the building is analysed, shall be determined using the following expression:

$$Fb = S(T) \cdot m \cdot \lambda$$

This force is a reaction of lateral earthquake load which accumulates downward of the foundation of the building.it can be described as largest earthquake load which damage the building at the lower part of the building. Mainly this failure is overcome by design base isolation for building (reference).

Fig (4) base shear mechanism and effects on the building (Ochshorn, 2009)

2.3 Load paths to the ground for the structure

Vertical loads:

Vertical loads of building act vertically on slabs and roof of building which are in the case of dead load (self-weight of slabs and frame components), this loads are combined with another vertical load which acts on the building during life of building(people load, movable load, snow load).

Horizontal loads:

Lateral loads are wind load or a seismic load, lateral loads depends on the building location and its height, loads act on joints then they are carried or by rigid joint, bracing system or concrete shear wall. This lateral resisting force system must be adequate to transmit forces towards lower floors then into foundation. In additional, the diaphragm floor and roof must be strong enough to be able to carry lateral loads this is satisfied by appropriate connection between lateral force system and diaphragm wall.

These load paths are significant for structure to satisfy equilibrium and avoid from overturning and excessive displacements.

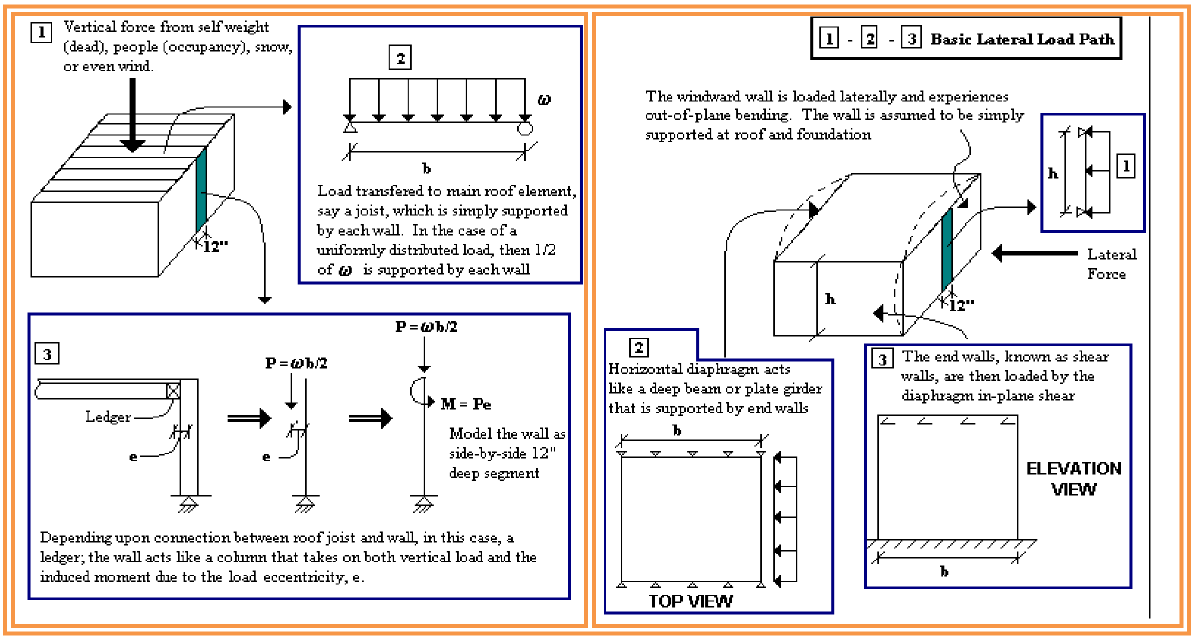


Fig (5) load path mechanism of vertical load and horizontal load(unknown)

Vertical loads must be accomplished equilibrium by soil reaction, the lateral loads, however, must be accomplished equilibrium by member stiffness, bracing and shear walls.
Low rises storey building should be provided its equilibrium by identifying its seismic load path to verify the validity of form construction of the building. The comparison of different of lateral force resistant system can move loads according to construction form.

2.3.1 in-situ reinforced concrete frame (shear wall lateral force resistance):

The normal load of low rises storey building starts in distribution dead and imposed loads on slab, the slabs are carried by beams then transfer into column, finally the pad foundation transmit all loads to ground. And lateral loads are distributed on the rigid external joints then transmits to the ground
However lateral earthquake forces which are transmitted laterally and subject to diaphragm slab. This lateral load attempts to overturn the slab when shear wall response the sway by moving the lateral force and turn it to vertical force and move down towards foundation and then ground. The shear wall should be designed to resist the predictable lateral earthquake force. The stiffer shear walls are capable to protect the building from distortion while, concrete building are brittle material its ductility depend on the high ratio of steel reinforcement. Well-designed steel reinforcement for shear wall are necessary to provide enough ductility for shear walls.

The slabs are subjected into vertical loads should satisfy bending resistance by longitudinal and horizontal steel reinforcement in the plane, shear force by slab thickness and drops for resisting punching shear. Furthermore beam section and its reinforcement are capable for resisting bending, deflection and shear force. On the other hand, the loads act on column may crush column under axial load or buckle it due to slenderness of column, then the adequate section and reinforcement are essential for resisting loads. Foundation thickness resist the shear failure into ground and dimensions of foundation satisfying the allowable bearing capacity and flexural can be resist by steel reinforcement.

The in-situ concrete frame can provide low ductility which defects structural resistant of building. Thus this property of concrete is not sufficient for earth quake resistant. Duggal insists that ‘The stiffness of reinforced cement concrete can be used to advantage, to minimize seismic deformations and hence reduce damage to non-structural members’

The behaviour of steel reinforcement is significant to be well-distributed on longitudinal and transverse direction (Dowrick,1977). Doubly reinforced beam, adequate cover, concrete quality and reinforcement quality provide high earthquake resistance for in-situ concrete (ibid). ‘The stiffness of RCC can be used to advantage, to minimize seismic deformations and hence reduce damage to non-structural members’

2.3.2 Steel bracing frame

Gravity loads (dead loads+ imposed loads) are applied on the precast hollow core or metal decking slabs then these loads are transmitted to secondary after that towards primary beam. These load transmissions are subjected from primary beams to column finally towards foundation and ground. The lateral loads (wind load+ seismic loads) transfer to diagonal bracing members towards columns and then to column and foundation and finally to the ground.

Slabs can deform and bend under gravity load, the hollow core flooring providing adequate resistance for bending and deflection. However the slab may buckle the beams laterally particularly in I-shape beam, therefore the reasonable stiffness and strength is important to resist lateral torsional buckling. This failure must be restrained in the H- column section.

For earthquake resistance, steels are highly strength to weight ratio of structural steel make the building ideally resist the seismic force (Duggal,2007). In comparison to reinforced concrete is more flexible but more laterally displaced than concrete. In other hand the cautions should be taken to bolt strength which needs to be greater than the strength of beam and column. This must be associated with avoiding excessive lateral sway and energy dissipation in connection(ibid). however providing lateral bracing assist the building to resist lateral loads of earthquake and wind loads. Moment resistant frame buildings have low energy dissipation, and then the lateral sway can be controlled into acceptable limit. The plastic hinge will occur in the beam, by this lateral force are transferred securely to column and in to foundation. In eccentric and concentrated braced system, the lateral seismic loads are transferred into diaphragm slab. The diagonal elements have a great portion of horizontal load and then transferred in the form of horizontal load into columns and into foundation.

2.3.3 Bearing wall constructed and in-situ concrete slab.

The applied load on slab are transferred to bearing wall then towards strip foundation and ground, the lateral loads act on slab then transmitted to wall and foundation. The loads transfers from slab to rigid masonry wall or reinforced masonry towards foundation

2.3.4 Timber frame

The loads transmitted from roofs towards column then into foundation

CHAPTER HREE: DIFFERENT FORM OF STRUCTURE BENEFITS AND VULNERBILITY AGAINST EARTHQUAKE

3.1 Reinforced concrete.

ADVANTAGES *are :*

- Concrete stiffness helps the structure to resist earthquake force.
- The ductility can be satisfied through steel reinforcement ratio. High amount of steel reinforcement ensure high ductility of reinforced concrete despite of concrete is brittle material.
- In-situ reinforced concrete is moment resistant frame. The moment frame resistance has a high performance of seismic load resistance. The lateral bracing is not necessary to be provided.
- Flexibility of adding redundant lateral resistance force to provide bi-directional load path. Although reinforced concrete is moment resistant frame but the reinforced concrete shear wall can be constructed together (referenece).

DISADVANTAGES

- Reinforced concrete is non-homogenous material which response non-linearly to highly seismic loads (Booth and Key, 2006)
- Diagonal cracks in the tension zone leads to burst stirrups outwards and induce buckling in concrete whatever concrete strength is (Duggal, 2007)
- Concrete cover need to be highly supervised during casting so as. Nevertheless, this makes degradation of concrete in the earthquake zones.
- Shear or bond failure in reinforced concrete happen at earthquake movements the reinforcement elongates more and fails in tensile the cracks remain bigger without interlocking again.
- The all frame elements must be highly detailed by reinforcement to respond high earthquake load. This may defect on buildability and economy.
- Movement joints must be avoided in concrete building and this movements mst turn to seismic movement joints to ensure that unit buildings do not come into pounding (Booth and Key, 2006).
- The needs of providing high degree of anchorage between elements and increasing laps of reinforcement.

3.2 steel buildings

ADVANTAES:

- Inelastic deformation cause by ductile frame this leads to formation and rotation in plastic hinges and redistribution of plastic moments. At this stage the structure possess more capability of resisting higher load such as seismic loads (Duggal,2007).
- Structural steel is ideal form of buildings due to high strength to mass ratio.

- Although a uniform distribution of bracing throughout building is undesirable, the braced frame can prevent lateral displacement and second order effects.

DISADVANTAGE

- Energy is dissipated in the bolt and connection even in moment resistant frame slightly dissipate energy, therefore the damping ratio is higher than concrete.
- The flexibility of steel structures may accommodate a large distortion, this causes damage of non-structural elements due to different capacity with steel in terms of ductility.
- High attention is generally needed in steel building during seismic action due to fail all element. Such as joints are yielded and compression struts tends to buckle.
- Bracing system provides a high resistance of earthquake however compression elements will buckle in the first seismic load then it is impossible to return into original shape.
- Fractures of elements due to excessive plastic deformation such as occur in the base plate in foundation and fracture in stiffeners. those are difficult to be remedied.

3.3 Masonry building

ADVANTAGES

- High compressive stresses capacity materials that support a big amount of loading
- Steel reinforcement can be accommodating through the walls. This practice is applied in the area of high seismically. Steel reinforcement can provide more shear strength
- Single storey building and two –storey building are not necessary be reinforced, normal masonry wall can withstand seismic force.
- In plane stiffness walls perform lateral resistance for earthquake by providing sufficient shear stress. This governs by cement mortars (Booth and Key, 2006)

DISADVANTAGES

- This form of construction is difficult to be adopted for multi-story
- Low tensile stress capacity and low ductility. Therefore walls break by effect of inter-storey drift.
- High masonry wall with respect to its breadth may induce shear failure or bending failure
- Irregularity in geometry of masonry wall defects by earthquake.

3.4 Timber

ADVANTAGES

- High ratio of tensile and compression at the same time to its weights. This can be accounted as a remarkable point in earthquake design.
- High ductile materials, most of energy can be dissipated in the joints (nail, screw and bolts). Therefore frame can sway laterally without failure.
-

DISADVANTAGES

- The brittle failure of timber cannot be remedied.
- High sensitive with seasonal change. Insects may devastate the frame.
- Highly susceptible to fire accident after earthquake, therefore it cause high damage of life

CHAPTER FOUR: POTENTIAL MODES OF FAILURE, THIER RISK AND IMPROVEMENT

4.1 Foundation failures:

4.1.1 Foundation Settlement:

Mostly foundation settlements result in additional stresses of the building which may produce by earthquake. The differential settlement is also potential settlements occur in irregular shape in plan of building during earthquake. These failures are end up with wall cracks and floor sagging

Fig (6) foundation settlement (Damage, 1990)   foundation settlement foundation settlement   (EERI, 2011a)

4.1.2 rocking moment on pad foundation :

Knappet et al (2006) states that horizontal force produced by earthquuake effects on the mechanism failure of pad oundation. The rocking moment induced by resultant of horizontal load of seismic and vertical gavity load of superstructure. The failure is idealised to two different coulombs slide failure. This can be found in fig ()

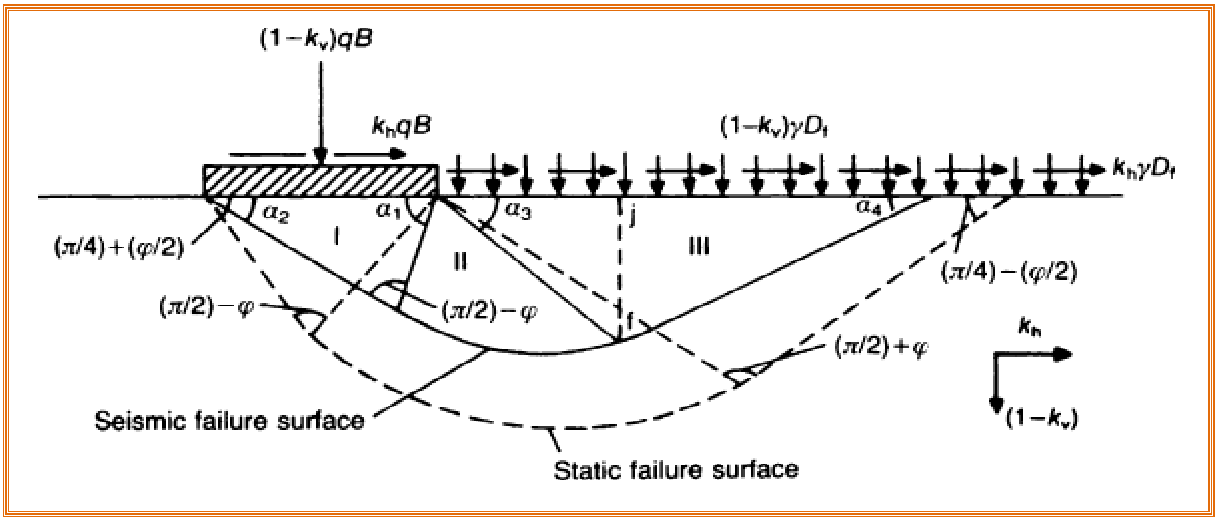


Fig7)) additional slide shear failure foundation due to seismic loading   (J.A. Knappett, 2006)

4.1.3 Landslide :

Phenomenon occurs frequently in building are constructed on the steep inclined hills which it relates to destructive earthquake loads. The failure caused by moving ground layer affected by horizontal force of earthquake.(Chen & Lui, 2005)

Fig(8) Landslide failure (NOAA, 2010)

Landslide failure (PHOTOBLOG, 2010)

4.1.4 Liquefaction

Tremendous amount of damage by earthquake is related to strength and stiffness reduction of ground. This phenomenon particularly happens in saturated soil, in which the foundations lie in the ground water table.

The mechanism of failure is based on increasing pore water pressure in the soil and decreases the attraction force between soil particles, then the soil capacity decreases. The failure occurs (Liyanapathirana,2002).

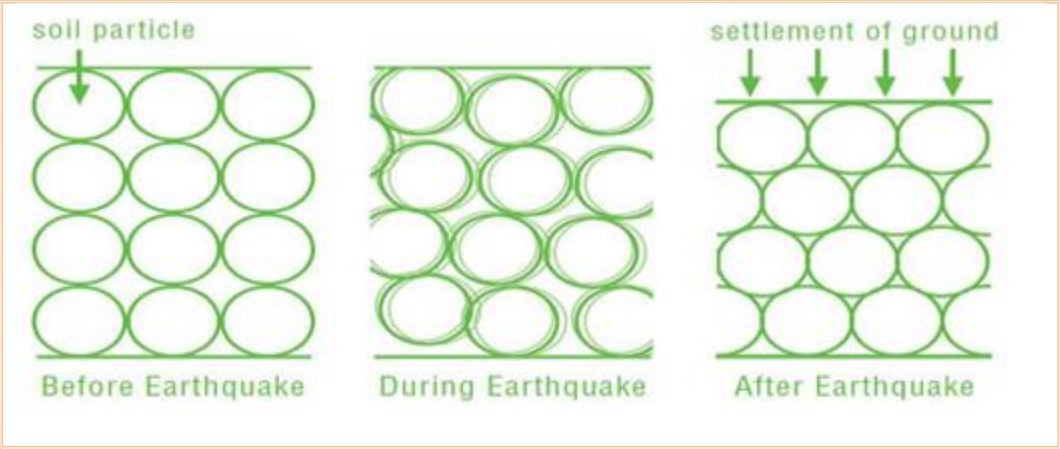


Fig (9) The mechanism of liquefaction ((RACKLEY, 2012)

l FIG(10) *liquefaction failure (Bhattacharya, 2007)*

4.1.5 Foundation connection:

The lack of secure connection between foundation and column lead to foundation connection failure during high level of seismic force. This mode of failure can be observed in concrete column and base plate of steel column, the reason behind vulnerability of column foundation interface is due to insufficient anchor for bearing resistance.

4.2 global failures:

4.2.1 Soft story

The most severe mechanism of building failure by earthquake loading, this failure mode is globally happen due to irregularity in the vertical direction namely different floor heights. The most frequently occur in the ground floor.

Fig (11) soft story failure (Alarcon, 2009)

4.2.3 Mass Irregularity:

This failure can be seen in the buildings are irregularly constructed or permanent loads are distributed unsymmetrically. Such as installation of equipment, tank or towers .or it may arise due to different floor levels in one unit building.

4.2.4 Vertical Geometric irregularity:

Building frame can rise failure due to irregularity of bracing stiffness in the vertical direction . it can be noticed from figure below column are unavailable in the ground level as well as shear wall only exist in the ground floor this can be described the most vulnerable condition during earthquake.

Fig (12) vertical geometry irregularity (Bachmann, 2002)

4.2.5 In-plane Discontinuity

This failure mode can rise from discontinuity load path, generally happens in bracing discontinuity in some levels of building as shown in fig (). The mechanism of failure can be idealised by insufficient section of lower levels to carry compression or tension loads.

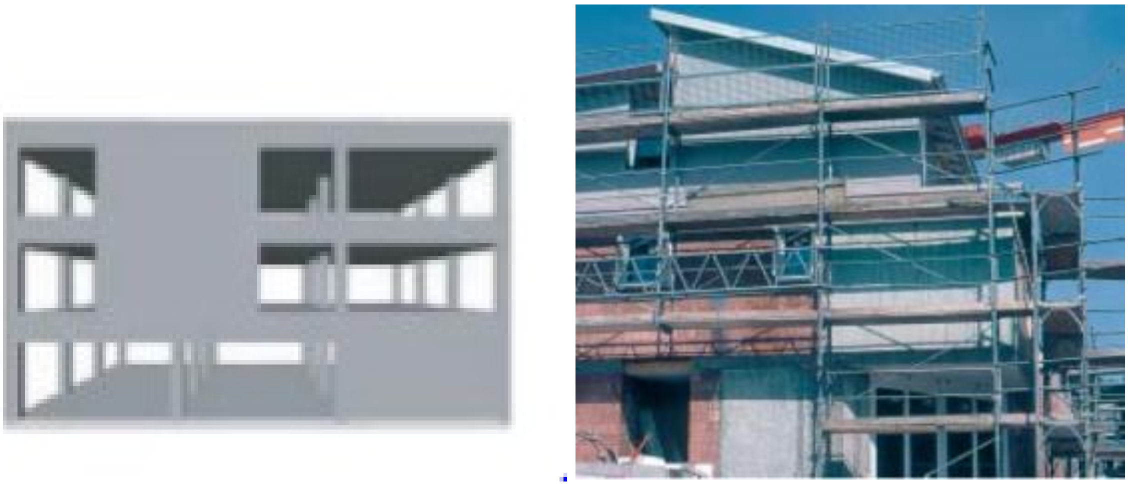


Fig (13) in-plane discontinuity (GEM, 2013)

(Bachmann, 2002)

4.2.6 Weak story:

This irregularity refers to the building presenting a floor lower resistance to lateral seismic force than other floors in the same building. Which can arise when strength and stiffness of lateral bracing is different from other stories, the members in that level cannot resist the loads are transferred by bracing. For example, the fig () shows that lower floor contains less wall and high in elevation particularly in hotels and hospitals.

Fig (14) weak story before earthquake (Nevzat Kirac, 2011)

Fig (15) weak story failure (Nevzat Kirac, 2011)

4.2.7 Re-entrant Corners

Irregularity of building in the plan leads to re-entrant corner particularly in the building configuring (L- X-H T) shapes or combination between these shapes. This due to the fact that these shapes generate many centres of rigidity

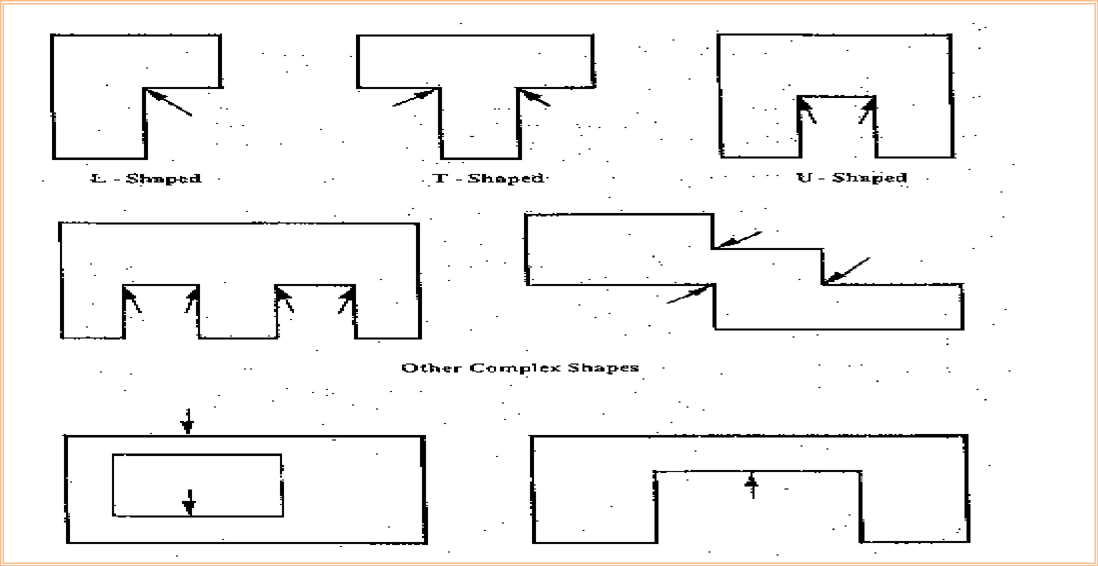


Fig (16) re-entrant corner in the buildings induced by earthquake (Arkansas, 1993)

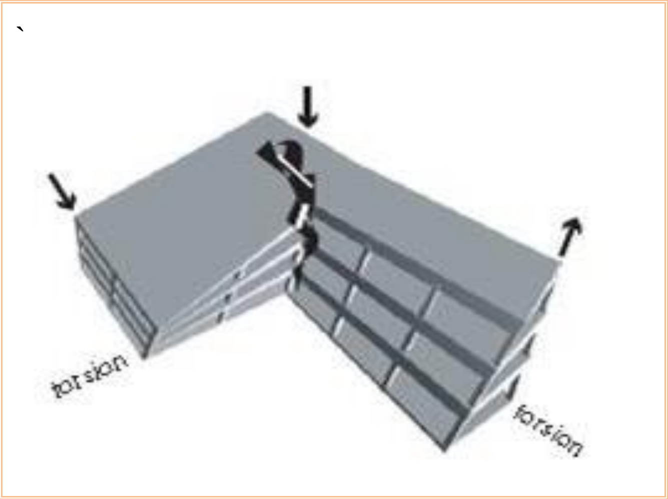


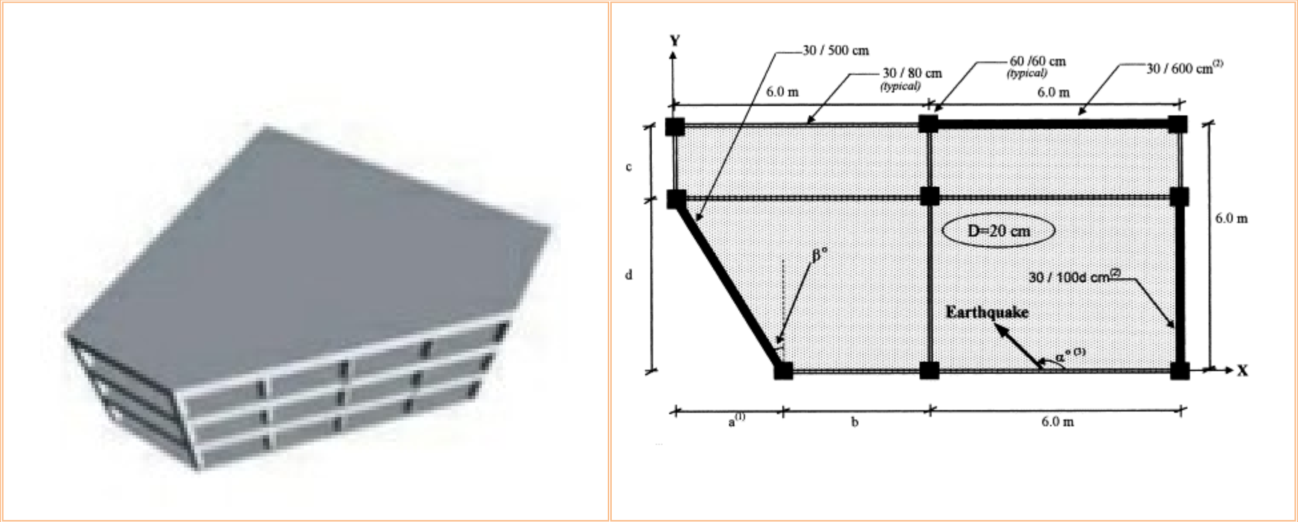
Fig (17) Re-entrant failure mechanism (GEM, 2013)

4.2.8 out-of-Plane Offsets

This mode of failure can rise in the building which have eccentrically lateral load resistance . For example columns the span length of the level are different of spans below or above.

4.2.9 Non-parallel Systems

Site condition may lead to design building in irregular shape while the site eges are not parallel to each other as shown in fig ()



Fig(18) Non-parallel phase building(GEM, 2013)   non-parallel lateral resistant force system (Semih S Tezcan, 2001)

4.2.10 Torsional Irregularity

Lateral seismic load tend to collect in the centre of mas of the building, this point should be coincide with the centre of the rigidity. If the condition does not satisfy torsional force induce around the centre of rigidity. The amount of this torsional moment depends on the eccentricity distance between the centre of mass and centre of rigidity. It can be observed in the buildings in different span length or unsymmetrical shear walls as shown in the fig ().

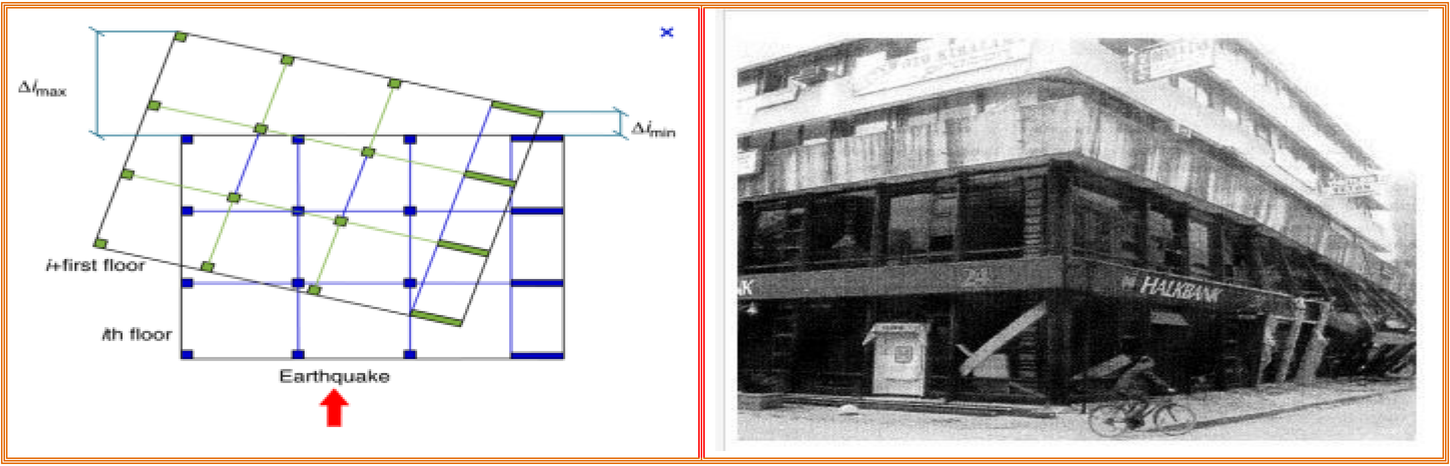
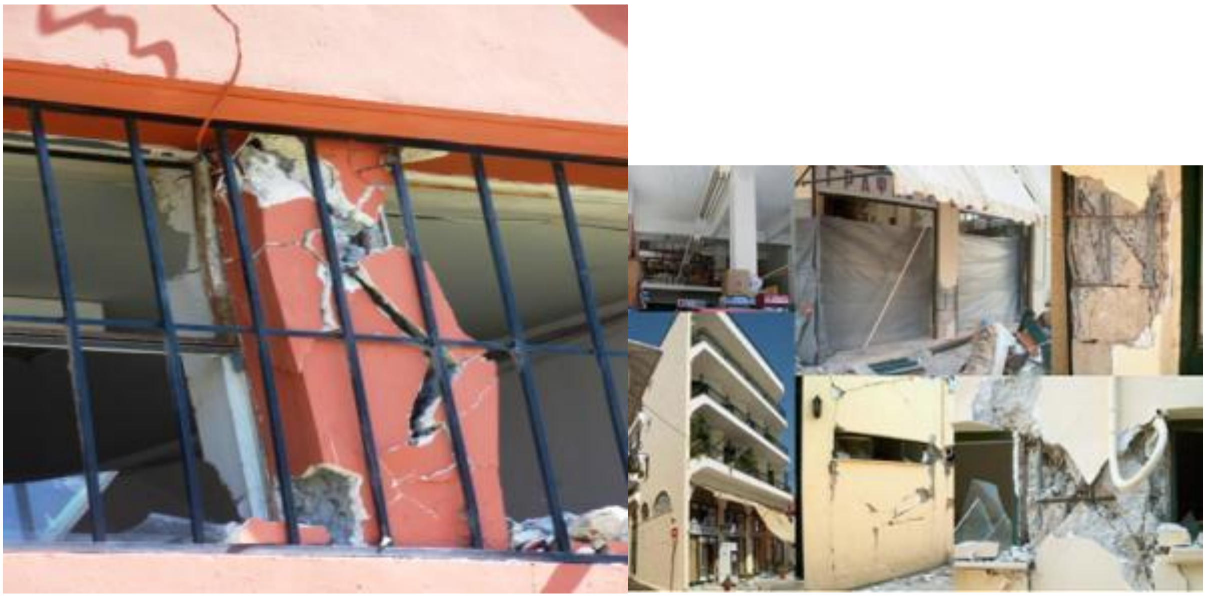


Fig (19) torsional irregularity mechanism and failure (Semih S Tezcan, 2001)

4.2.10 short column failure:

(Bachmann, 2002) determines that short column perform negatively during earthquake. in the fact this short column which are relatively stocky in comparison to their length, considering that these column are less stiffness than beam and slab. The same mechanism of weak column and strong beam will develop in these columns. Therefore the shear pattern failure develops in the column.



FIG(20) SHORT COLUMN FAILURE(EERI, 2013) SHORT COLUMN FAILURE (Anastasios G. Sextos, 2011)

4.3 Detailing failure

4.3.1- Brusting failure in Column

the failure in column develops by increasing axial load of seismic force. Which is transferred from diapgram floors or bracing to column.

4.3.1-Buckling of main Reinforcement of Columns

Main steel reinforcement buckles dramatically in the column in the case of lack of stirrup

4.3.2 Shear Movement

These may induce by several ways

4.3.2.1 in column

This may observed from fig () due to irregularity in elevation shear force acts on the column at the lower column of higher part of building**.** Mostly happen in the column in the first level. Therefore, the column prone to failing due to low shear resistance, which might be developed by steel reinforcement in the concrete compatibly with concrete cross section of column.

4.3.6.2 Cold joint in column

This mechanism of Shear failure develops in the columns casted in different stages. By this the shear resistance should be very low to resist inherent shear force induced by lateral force of the earthquake. the separation can develop between column and slab and then the failure may be more catastrophic than expected.

Fig (21) failure due to poor detailed reinforcement and poor construction (Y B Marhatta, 2007)

4.4 Masonry failure

4.4.1 Free standing Masonry cracks:

The ground motion tends to act on the free supported edges walls, which cannot respond this load by weak interaction tensile stress between mortar and units. This weakness of bonding causes cracks on the wall due to overturning moment produced by mass and ground motion (IAEE,1986). These failure can be seen in The retaining walls and fence which depend on dimension and position of the walls as illustrated in the fig()

4.4.2 Shear sliding in Masonry :

The mode of rocking failure is developed in the masonry building are related to global response of building to seismic force (Rush,2007). The tension cracks arise in the walls in in the diagonal shape. Mostly this cracks starts in the corner of the opening (Arya, 1986).

4.4.3 Pounding in Masonry

This mechanism of failure can be noticed in contacted area between two buildings. The inertia loads in each building produced by seismic force transferred to the other building. Then building movement induce a collapse connection area **(Rush,2007)**. This mode of failure mostly happen in residential areas when building attached back to back or side to sides.

4.4.4 Rocking in Masonry

The mode of rocking failure is developed in the masonry building are related to global response of building to seismic force

Fig(22) failure modes in masonry (Rocking, shear sliding and Pounding)(Rush, 2007)

4.4.5 free standing masonry wall:

free standing wall overturn due to seismic fore regarding to its weight and obviously very small shear capacity between unit masonry with cement mortar (guidance). The wall acts as a shear wall and its damage depends on stiffness and with to height ratio, therefore the crack pattern reflects on this ration.

4.4.6 wall enclosure without slab

the cracks will arise in the wall without slab due to bending moment induced by lateral fore of earthquake while the cracked wall is supported by two orthogonal walls at the ends ()

4.4.7 roof of two walls

the damage or collapse may happen in the walls which supports diaphragm slab during earthquake events . This can be produced by transmitting inertia force acted on the slab in forms of shear force or overturning moments. This failure is characteristics of the slab failure when the slab out of phase from supports (Rush, 2007)

4.4.8 Roof on the enclosure walls

The walls in different direction may experience different damage. This causes transferring inertia force reversely proportional with the stiffness.

4.4.9 weak connection between slab and wall:

The slab may fail in masonry buildings if there is inadequate connection between walls and slab.

All masonry failure are resulted from masonry walls are weak in tension as well as in compression and no ductility to accommodate inter-story drift. Performance of connection between two orthogonal walls is low. Opening positions in the slab have a pivotal role in reduction of stiffness and fail the wall due to shear sliding. The inertia effect of the wall is small in length and height with respect to thickness of wall (Rush, 2007).

4.4.10 partially infill masonry wall

This kind of collapse are common in the building that have openings at the top of infill wall. The columns become partially restrained by masonry so the mechanism of short column failure arise in that column(G. Uva, 2012)

Fig (23) failure in column due to partially infill masonry(Bachmann, 2002, G. Uva, 2012)

4.5 potential failures in the wooden building

4.5.1 Roof tiles sliding:

Mainly this failure arises when there is no adequate connection between roof frame and tiles during earthquake.

4.5.2 Column to girder joint failure

The joints will deteriorate if the loads of roof increase due to effect of lateral force

4.5.3 sliding of joints

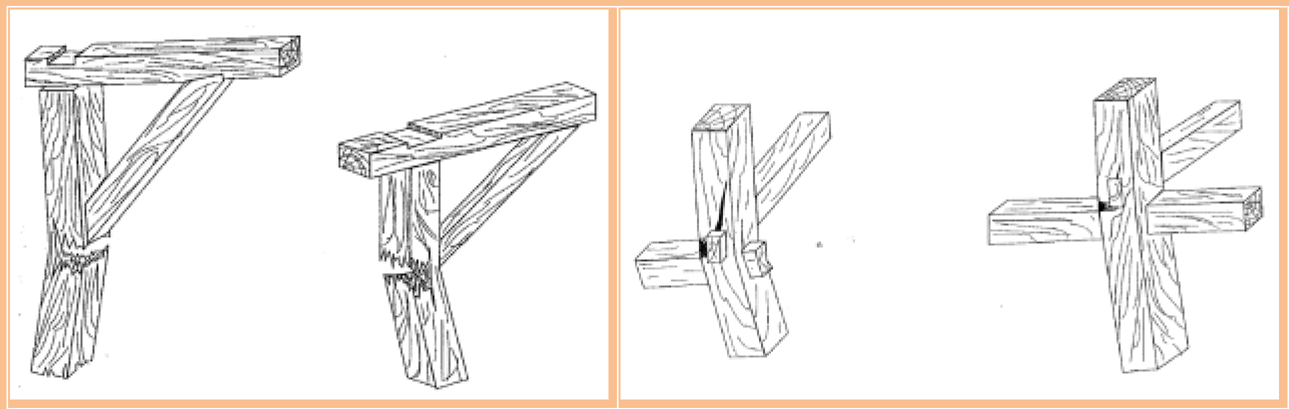
this arise by lateral force acting on the joint and develop inter-story drift.

4.5.4 wooden gable frame

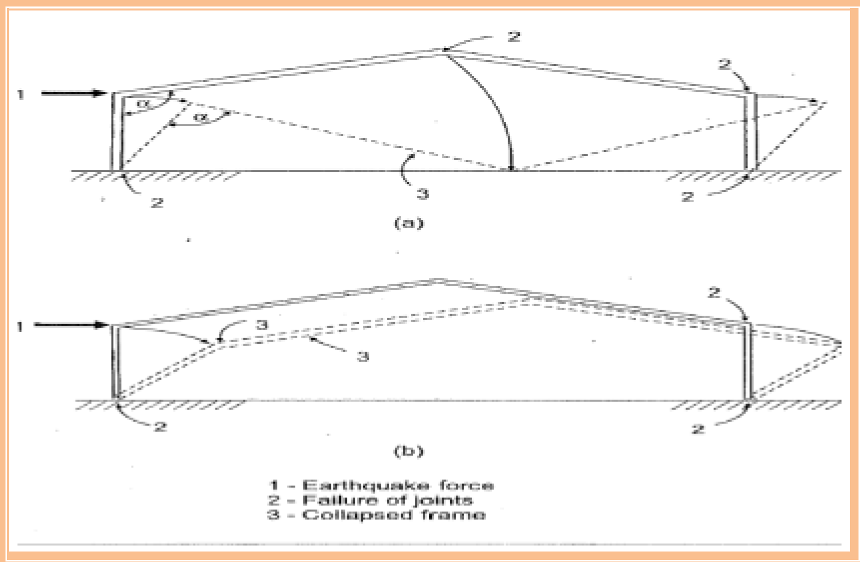
This due to rapture of chord of roof truss while earthquake force applied.

4.5.5 fire accident

this can be accounted to most severe collapse during earthquake because wood is high flammable



Fig(24) failure mode of column to girder joint in timber building ()(Rush, 2007)



Fig(25) failure mode of wooden gable frame in timber building ()(Rush, 2007)

CHAPTER FIVE: SKETCH OF DETAILING STRCTUTRES RESPONSE OF EARTHQUAKE

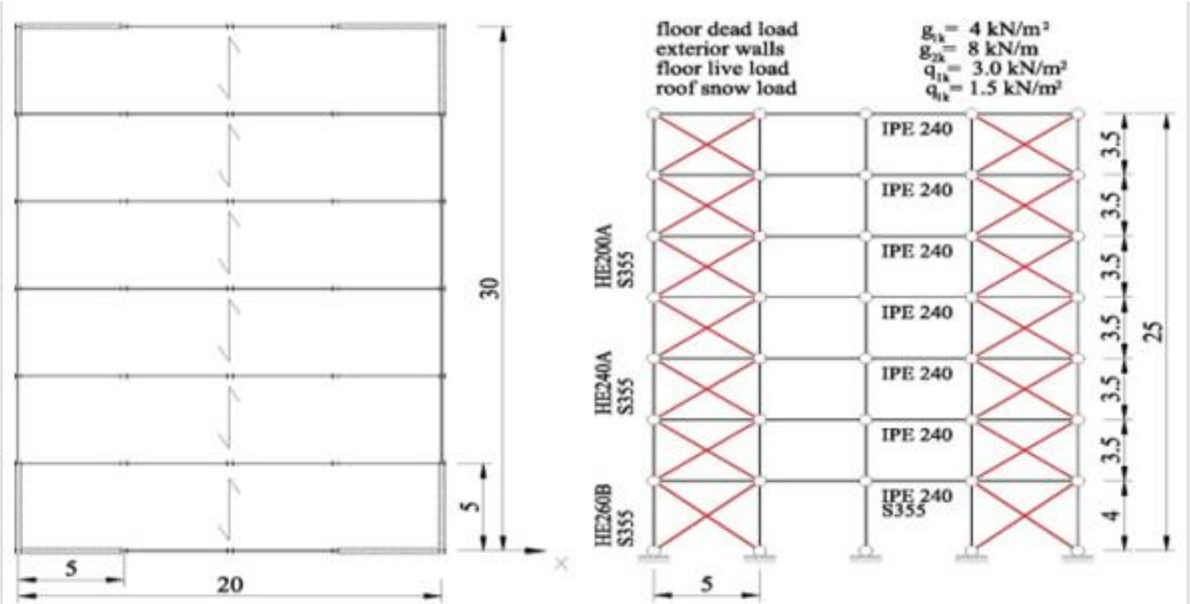
5-1 ensuring for foundation problems during earthquake

- It is essential to collect data about soil profile by taking samples of (standard penetration test (SPT) and cone penetration test (CPT). In addition to laboratory tests such as shear wave velocity and cyclic triaxial or resonant column laboratory to ensure the behaviour of previous ground motion (Booth, 2008)
- Investigating the availability and level of the ground water level. High attention needs to be taken in high level of water level area by designing foundation which protects the building from potential of liquefaction failure.
- Avoidance from instability of ground slopes in order to avoid landslide which may affect by earthquake.
- According to BS EN 1998-1, Foundation volume must be adequate to resist overturning moment may induce by earthquake.
- Foundation must have enough friction force to resist the total shear force applied on foundations.
- Sufficient anchorages between column and foundation needs to be satisfied by providing appropriate amount of transverse and longitudinal in the column foundation connection in concrete form or rigid base plates in steel building.
- Provide base isolation for high seismically area

5-2 ensuring for irregularity in building configurations

5.2.1 Horizontal irregularity

5.2.1.1- Torsional irregularity: this can be avoided by distributing lateral resistant force system symmetrically and uniformly in plan to coincide both centre of mass and rigidity at the same position.



Fig(26) symmetrical distribution of lateral resistant force system to avoid torsional irregularity (Metelli, 2013)

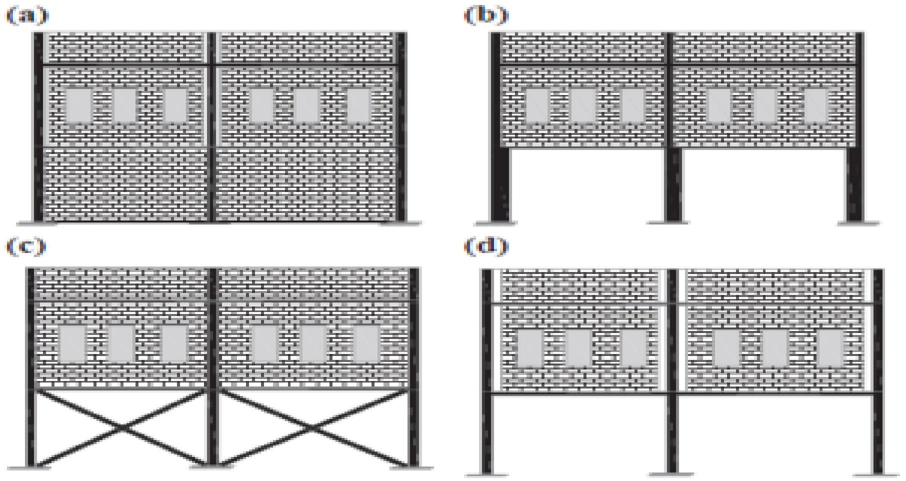
5.2.1.2 Re-entrant corners: this can be addressed by separation the building into simple shapes. When two unit buildings to be apart by seismic movement joints which needs to be enough to ensure the pounding will not occur due to different mode of vibration of each building.

Fig(27) dividing building into simpler shape to avoid re-entrant corner (Korkmaz, 2011)

5.2.2- vertical irregularity

5.2.2.1 - weak story

(Korkmaz, 2011) has set out this solution to control weak story according to the fig(). Firstly, the solution is to create seismic movement joint between wall and column. Second solution is to provide consistent stiffness throughout the height of the building. or infill masonry for weaker floor if possible or adding concentric or eccentric braced system.

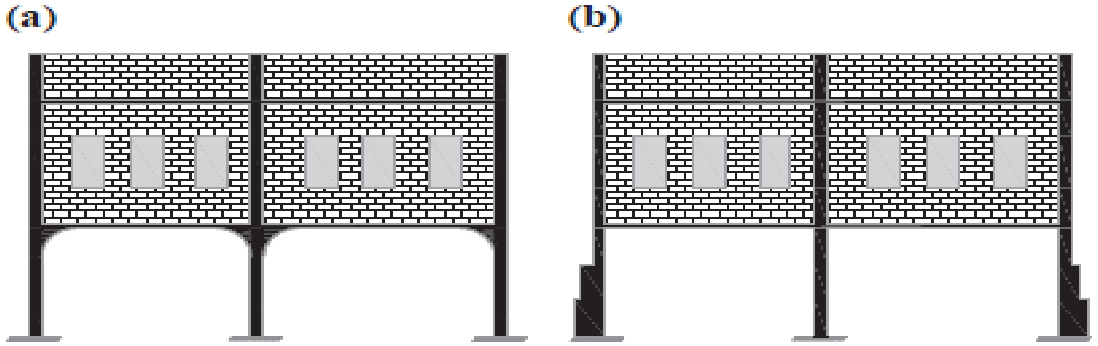


Notes: (a) add walls; (b) increase cross-sections of columns; (c) add steel bars; (d) isolation gaps

Fig (28) improvements of weak story failure (Korkmaz, 2011)

5.2.2.2 Soft story

this can be tackled by strengthening column stiffness to provide consistency in stiffness. Another solution is to adding bracing system for that level. Alternatively to provide additional column or providing vaults at ground floor or adding external buttresses.



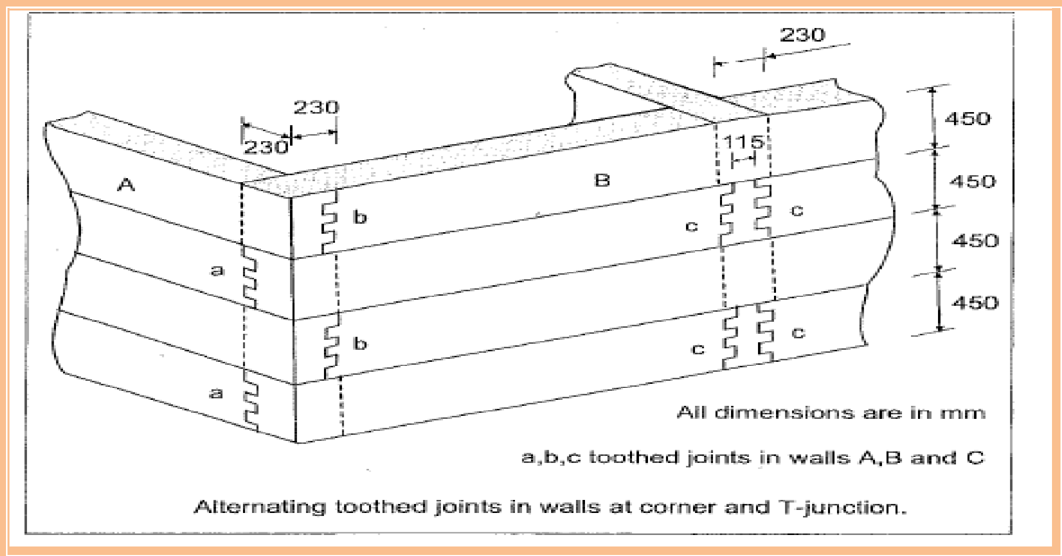
Notes: (a) vaults; (b) external buttresses

Fig(29) improvements of soft storey failure(Korkmaz, 2011)

5.3 Improvement of masonry failure

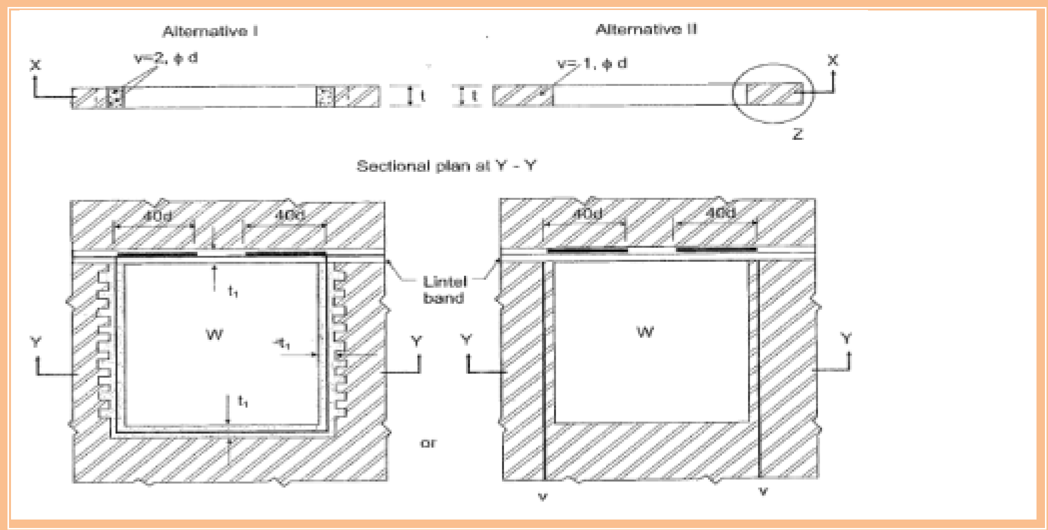
1- Utilising mortar that have a high strength in adhesion such as cement mortar or lime mortar
2- Thickness of walls should be adequate to maintain inertia and strength. This can be achieved by providing vertical joints between perpendicular walls or horizontal reinforcement beam to tie orthogonal walls

Fig() improvements of soft storey failure(Korkmaz, 2011)



Fig(30) improvements of simber wall constrution by teething joint(Rush, 2007)

3- Limiting the opening size with respect to required circumstance for each opening according to standards are considered for this reason.Total length of opening should be less than the wall length and the vertical distance between two opening should be more than60 cm or or half width of smaller opening. If these criteria do no comply then the openings should be framed by box reinforced concrete (Rush, 2007)



Fig(31) improvements of simber wall constrution by teething joint(Rush, 2007)

4- Attention needs to be taken in providing anchorages between wall and other elements such as foundation slab as well as column- beams in the infill walls. This is applied by using steel dowel bars at corner and T joints the figures below show the details of dowels.

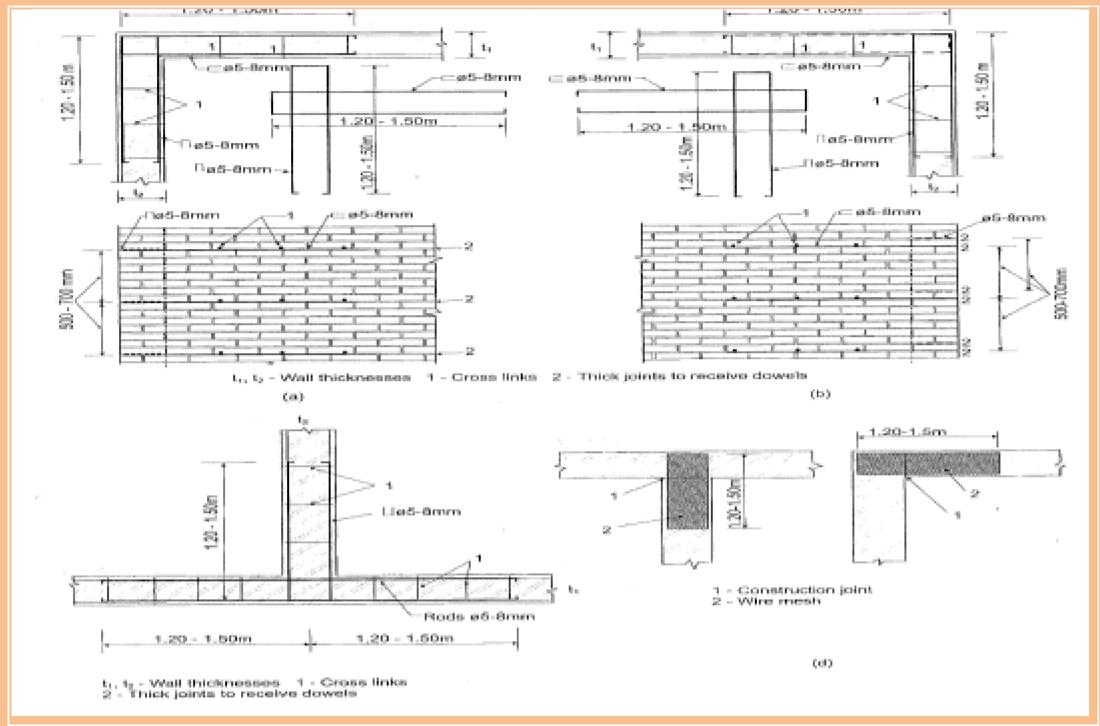


FIG (32) improvements of masonry construction by dowing and tie beams(Rush, 2007)

Fig (33) improvement the masonry wall against earthquake loading (Bachmann, 2002)

5- **Separate non-structural masonry from building frame with soft joint:** (Bachmann, 2002) indicates that masonry buildings should be separated from Skelton of building due to different vibration mode of each material. This joint can absorb some deformation. the necessary thickness of te joint is typically 20 to 40 mm. it should be rubber, cork or Styrofoam which depends on the stiffness of building and masonry.

Fig(34) providing joint between frame and infill masonry(Bachmann, 2002)

5.4 Improvements measures for timber construction imposed to earthquake:

Wooden construction can be improved to resist earthquake loads according to codes and practices. The detailed construction of wooden building these elements need to be constructed

1- Stud wall
2- Bearing wall
3- Brick nogged timber frame
4- Joints in wall
5- Foundation

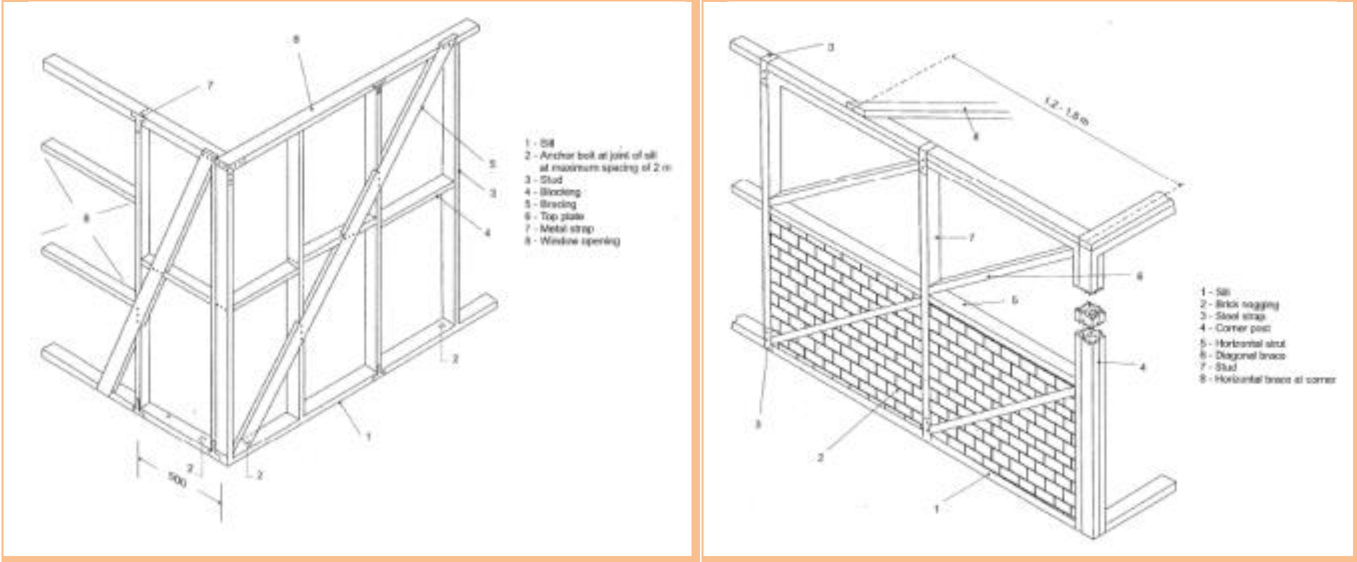


Fig (35) detailed of timber wall(stud walls) (Rush, 2007)

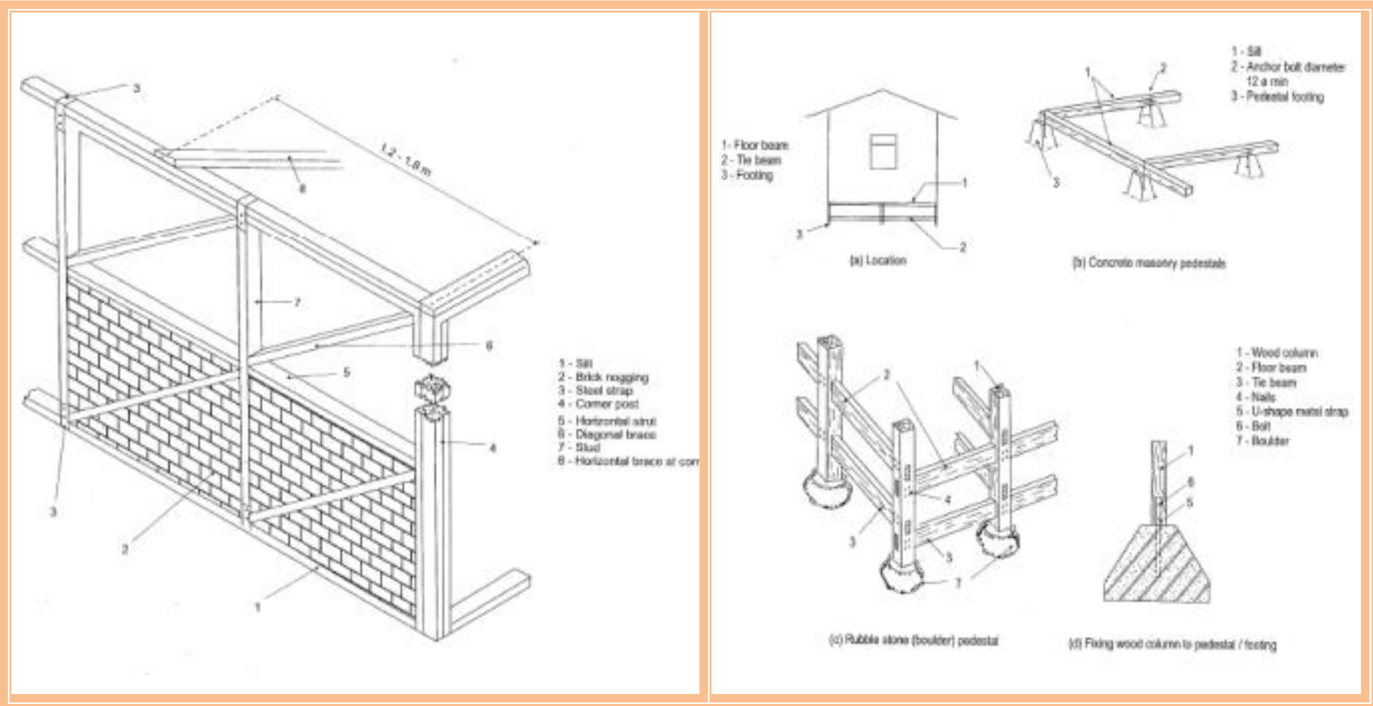


Fig (36) detailed of timber wall(bearing walls) and foundation details(Rush, 2007)

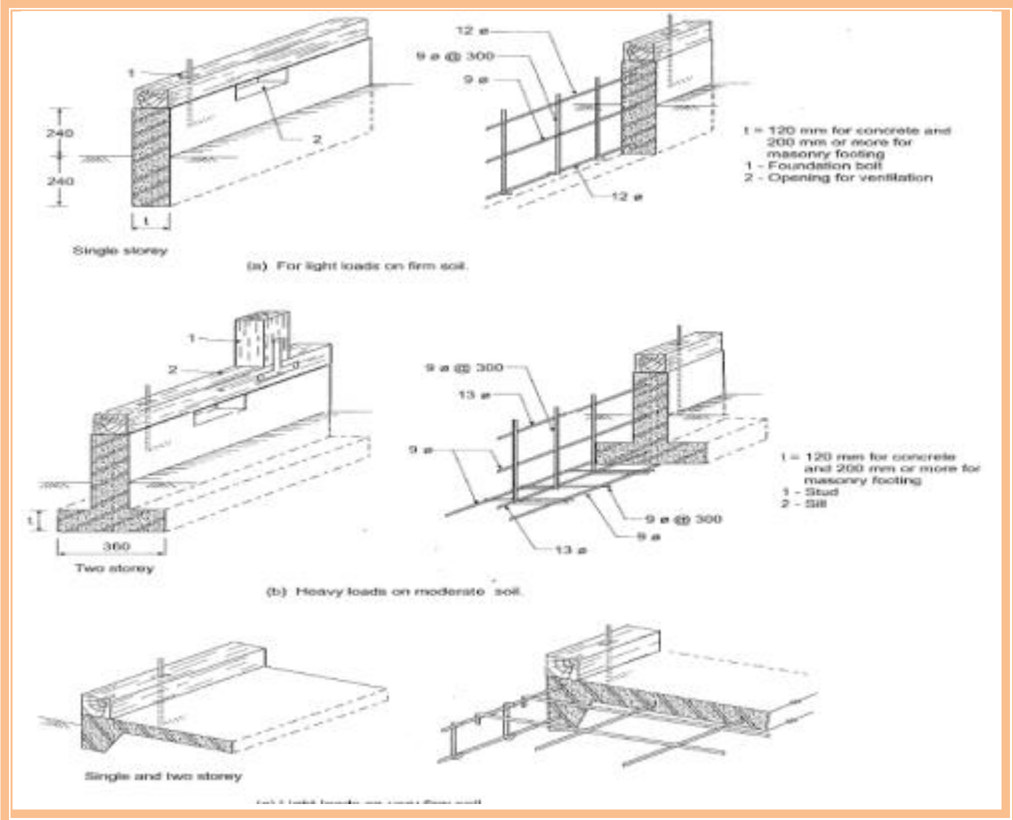


Fig (37) detailed of timber construction foundation details (Rush, 2007)

5.5 Reinforcement detail in concrete building:

According to ((Rush, 2007) there are some points to be measured when placing reinforcement details in the structure. The weakness will take place into the structure if the details are not placed properly, which are:

- Minimum clear cover to the reinforcement: For slabs (15mm), Beams (25mm), and Columns depends on the size of the columns, e.g. column with 450mm thickness, the covers require to be (40mm).
- The longitudinal bars should be tied properly by thin wire with transverse bars stirrups and links. Furthermore, the reinforcement should be overlapped appropriately. For instance, the minimum overlap for plain mild steel is (45*diameter of the bar), high strength deformed bars is (60*diameter of the bar).

- The ends of stirrups and links bars should be bended to resist seismic forces. Likewise, mild steel bars are bended 181 degree and for deformed bars are 135degree as illustrates in figure (2).

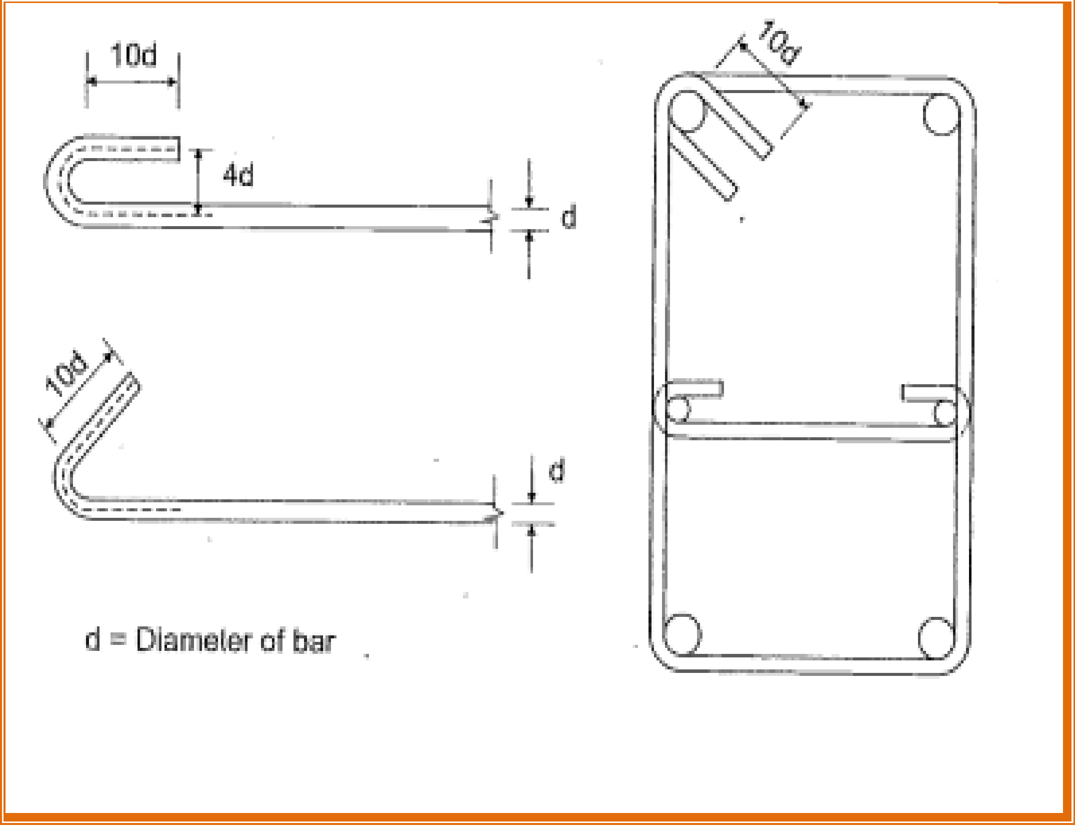


Figure (38) Hook's at end of links (Kaikan K. (2001))

Anchors are used for detailing reinforcement between column beam connections as indicates in figure (39). The reinforcement in columns and beams need to get into each other and hook at the end by 90 degree.

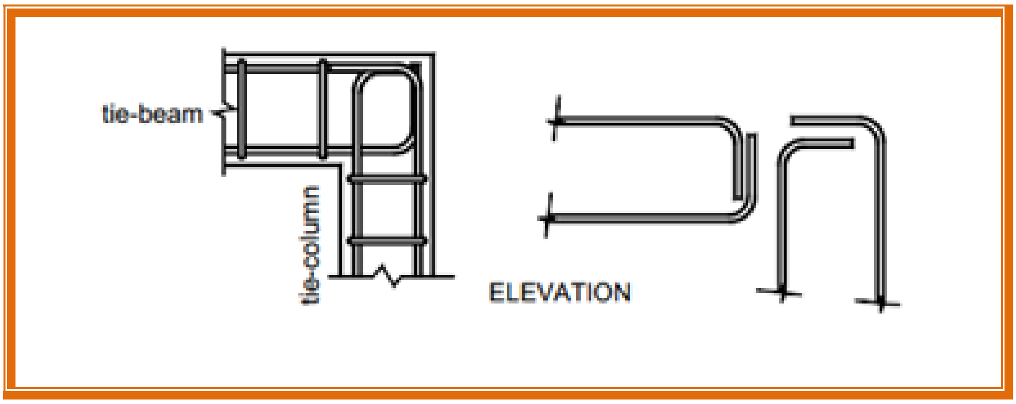


Figure (39) Anchorage of tie-beam and tie-column longitudinal reinforcement (EERI, IAEE, (2011), cited in Alcocer et al., (2003)).

When the depth of beam exceeds 300mm, there must be confinement of RC column by tying at the top and bottom joint. Additional U-shaped stirrup is placed at the mid height of the tie beam, which indicates in figure (40).

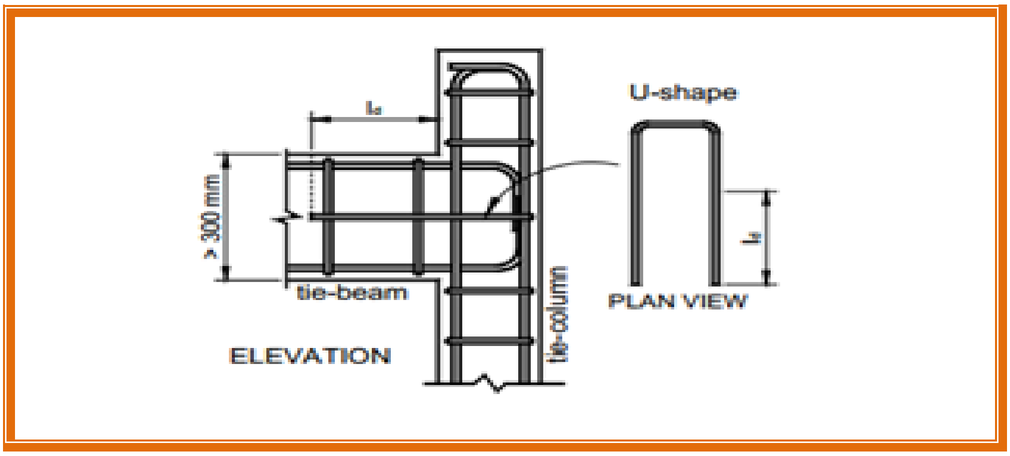


Figure (40) Additional confinement for vertical reinforcement in the tie-beam and tie-column end joint region. (EERI, IAEE, (2011)).

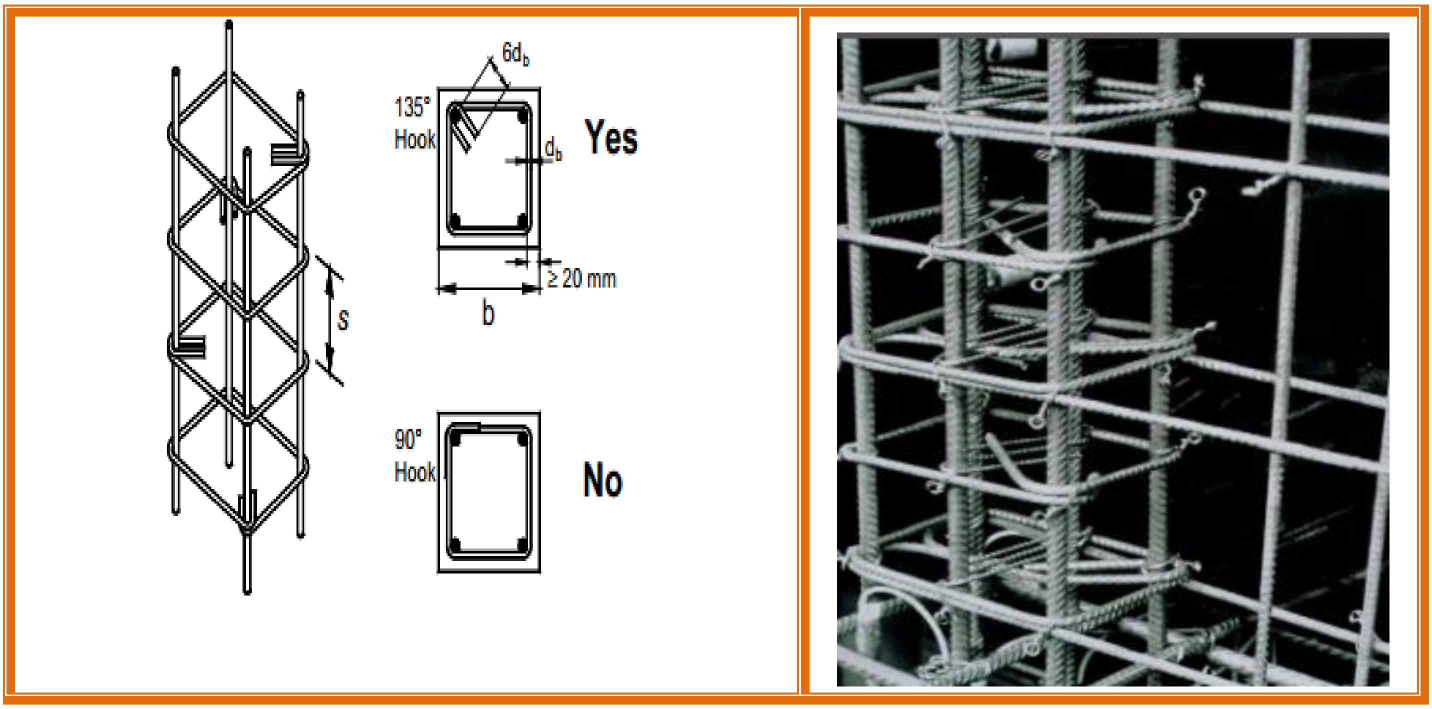


Figure (41) Tie layout and detailing of reinforcement in columns. ((EERI, 2011b)).

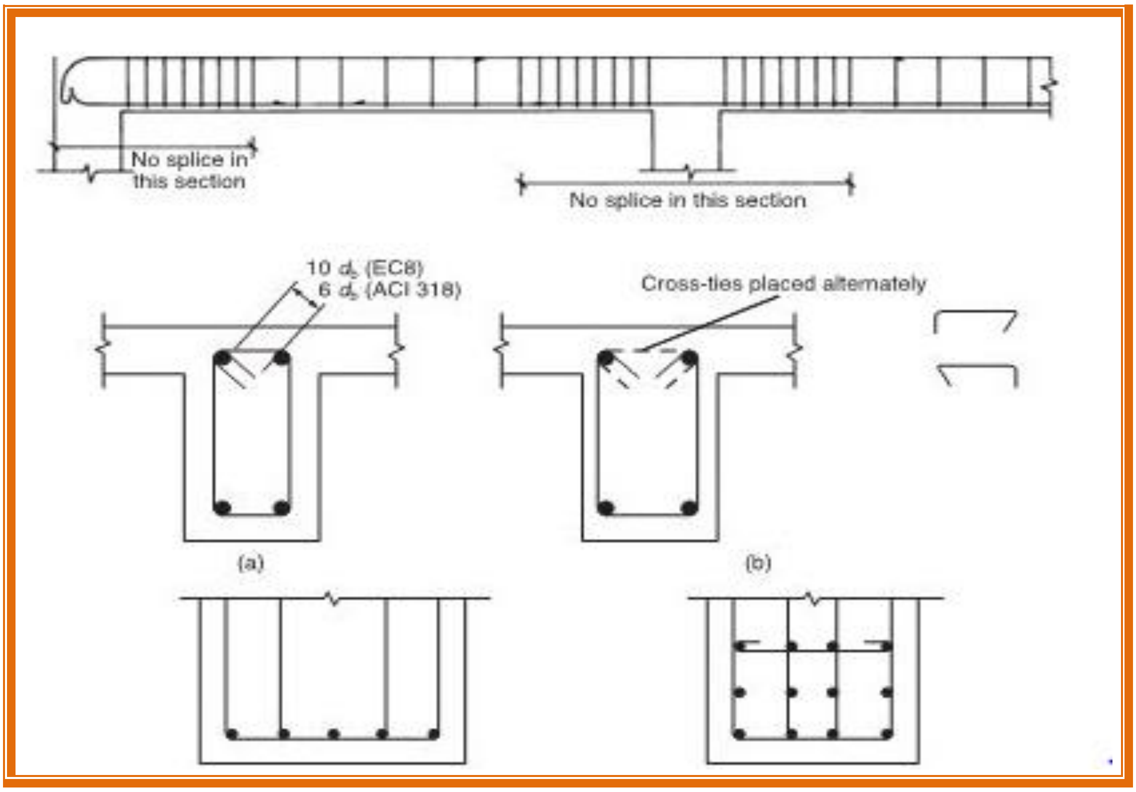


Figure (42) the detailing of ductile beam reinforcement(Booth and Key, 2006)

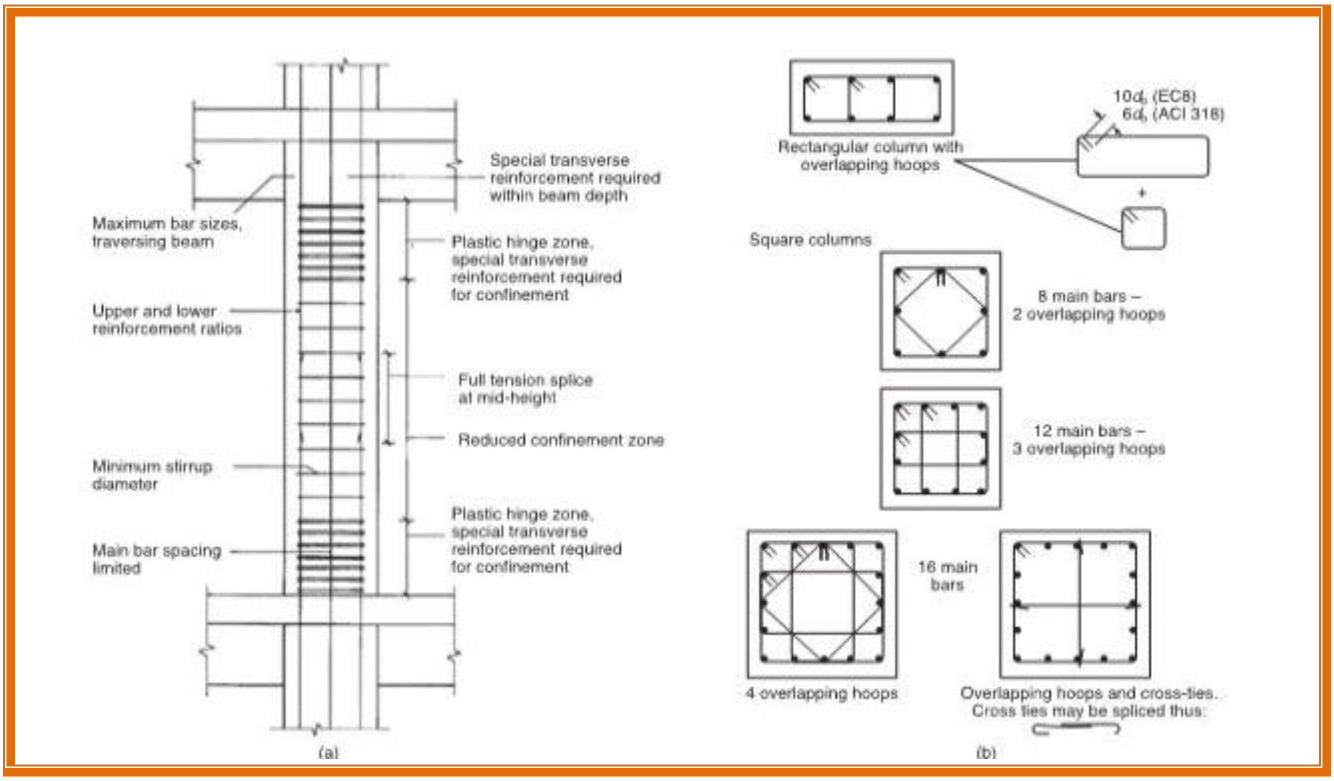


Figure (43) the detailing of ductile Column reinforcement (Booth and Key, 2006)

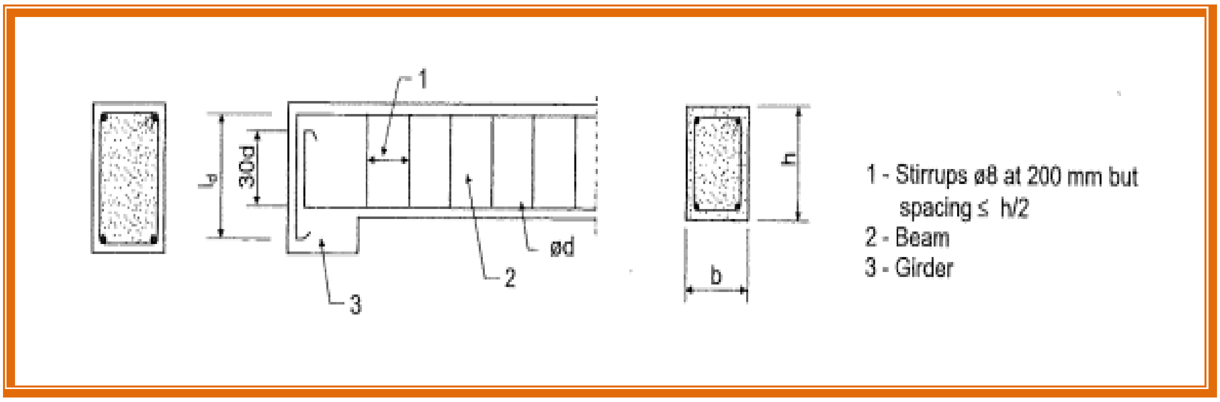


Figure (44) Connection between beam and girder (Kaikan K. (2001)).

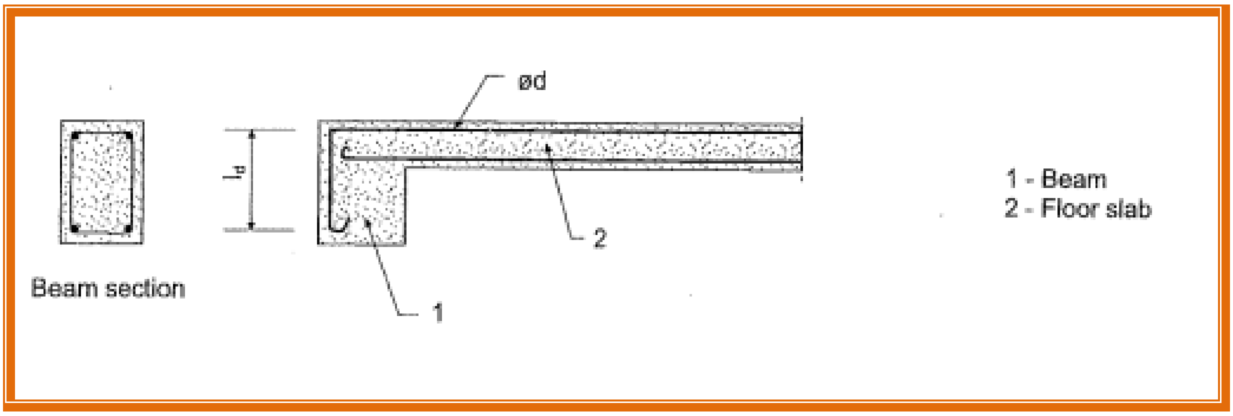


Figure (45) Connection between floor slab and beam (Kaikan K. (2001)).

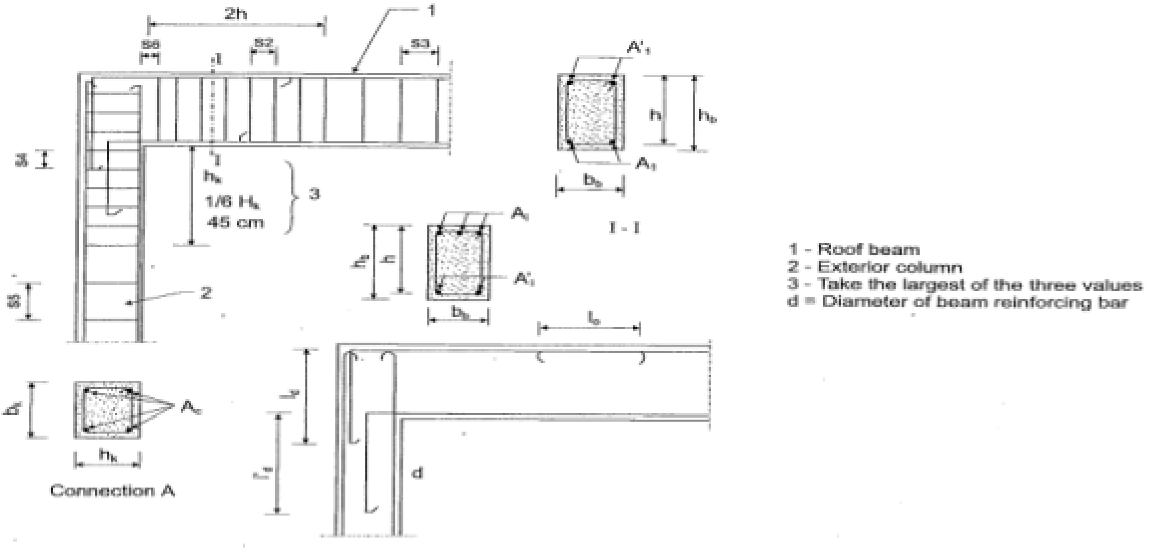


Figure (46) Connection between roof beam and exterior column (Kaikan K. (2001))

5.6 Steel detailing in steel building

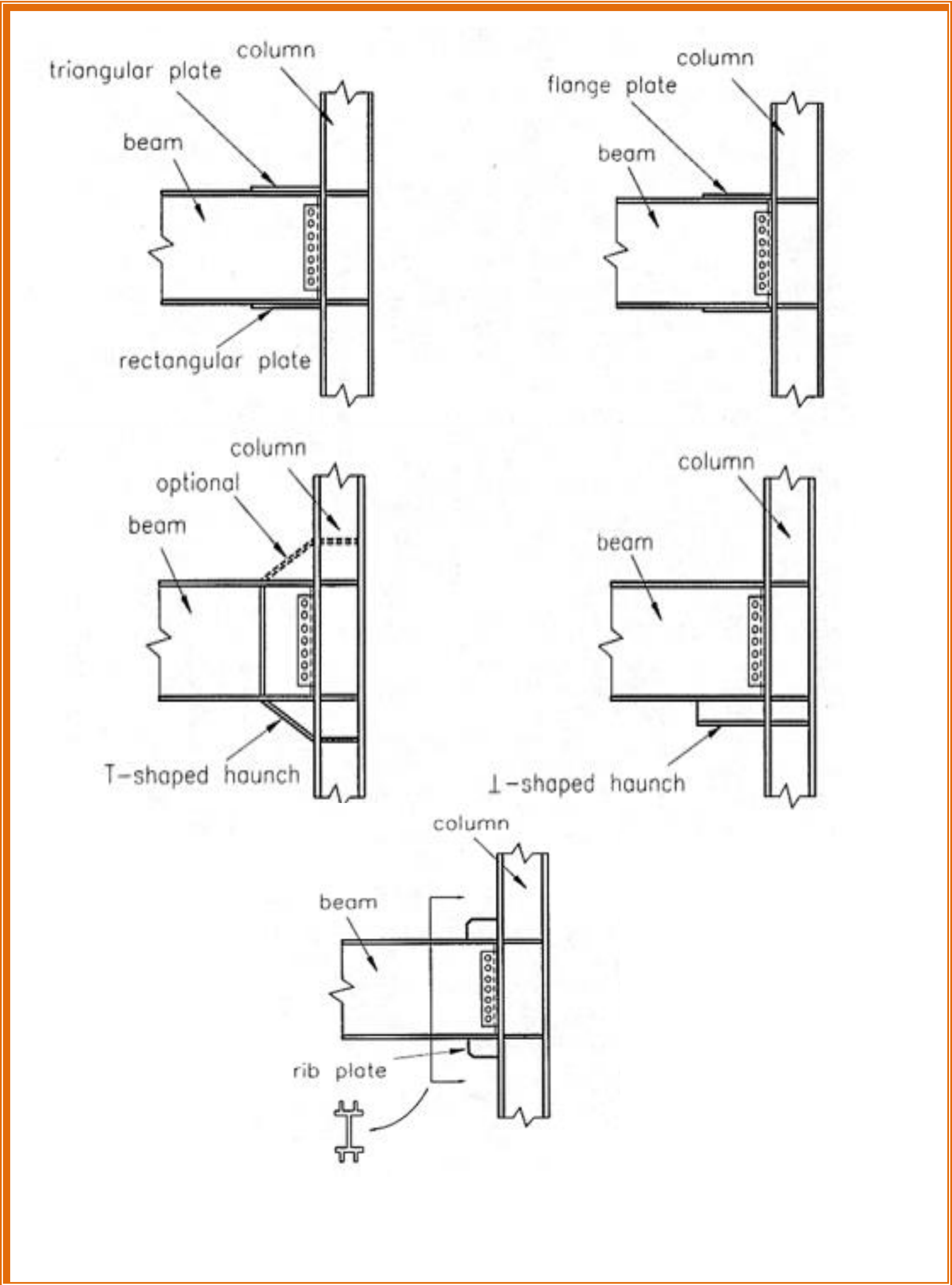


Figure (47) Reinforced moment connections for steel structure with (Cover plates, welded flange plates, triangular haunches, straight haunch, and rib plates. (Uang C-M., 1998).

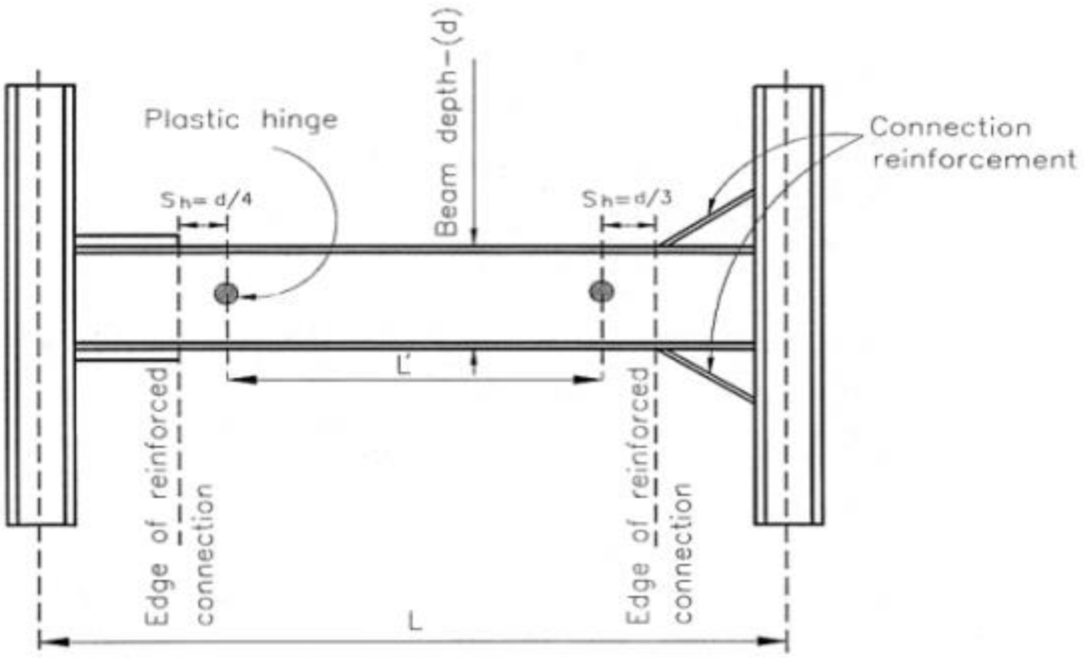


Figure (48) The assumption of location of plastic hinges. (Uang CM., at el. (1998) cited in Interim Guidelines Advisory No.1, SAC (1997)).

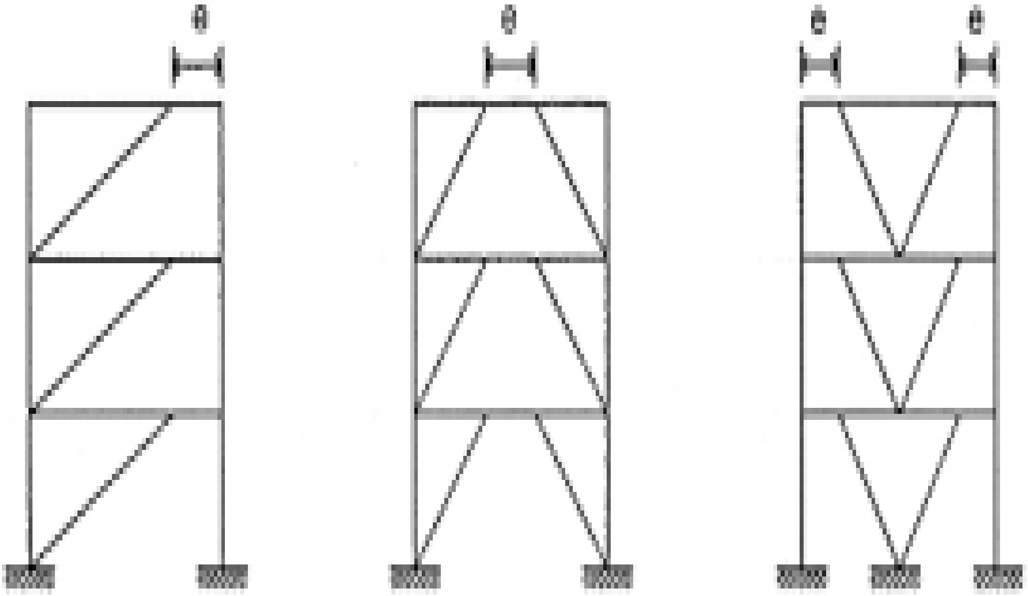


Figure (49) Typical Eccentric Bracing System configuration (Uang C-M., 1998)

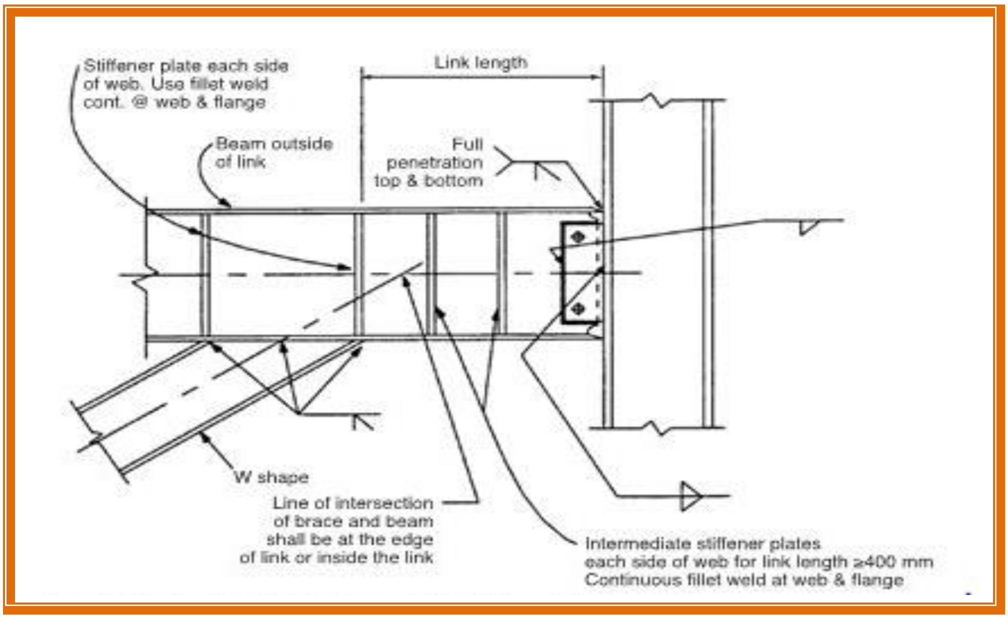


Fig (50-a) typical detail of eccentric bracing (Booth and Key, 2006)

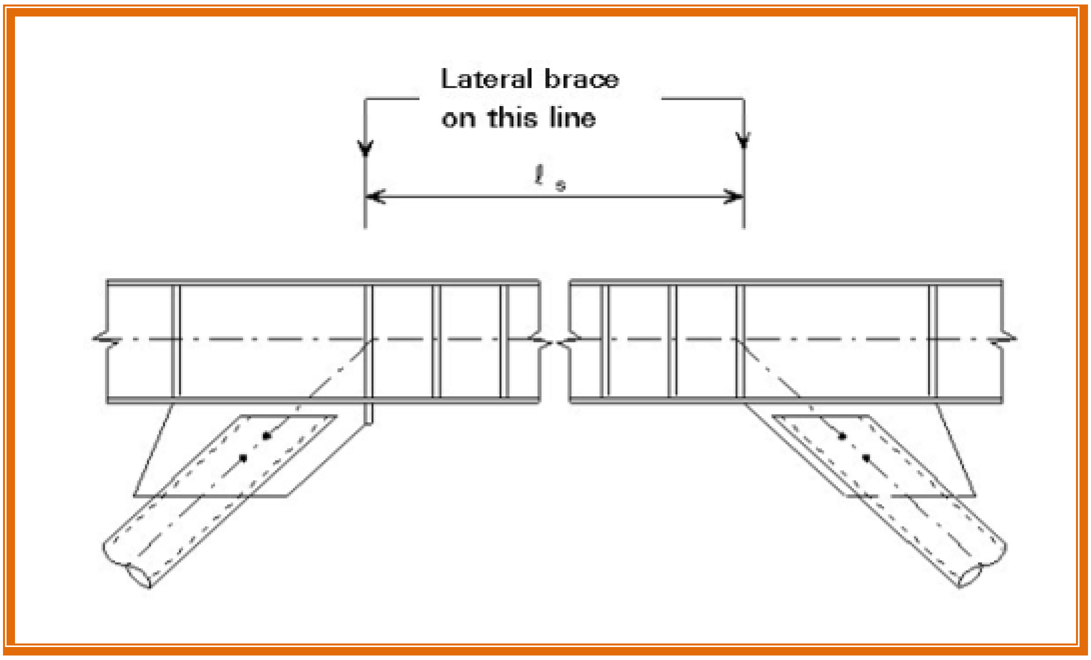
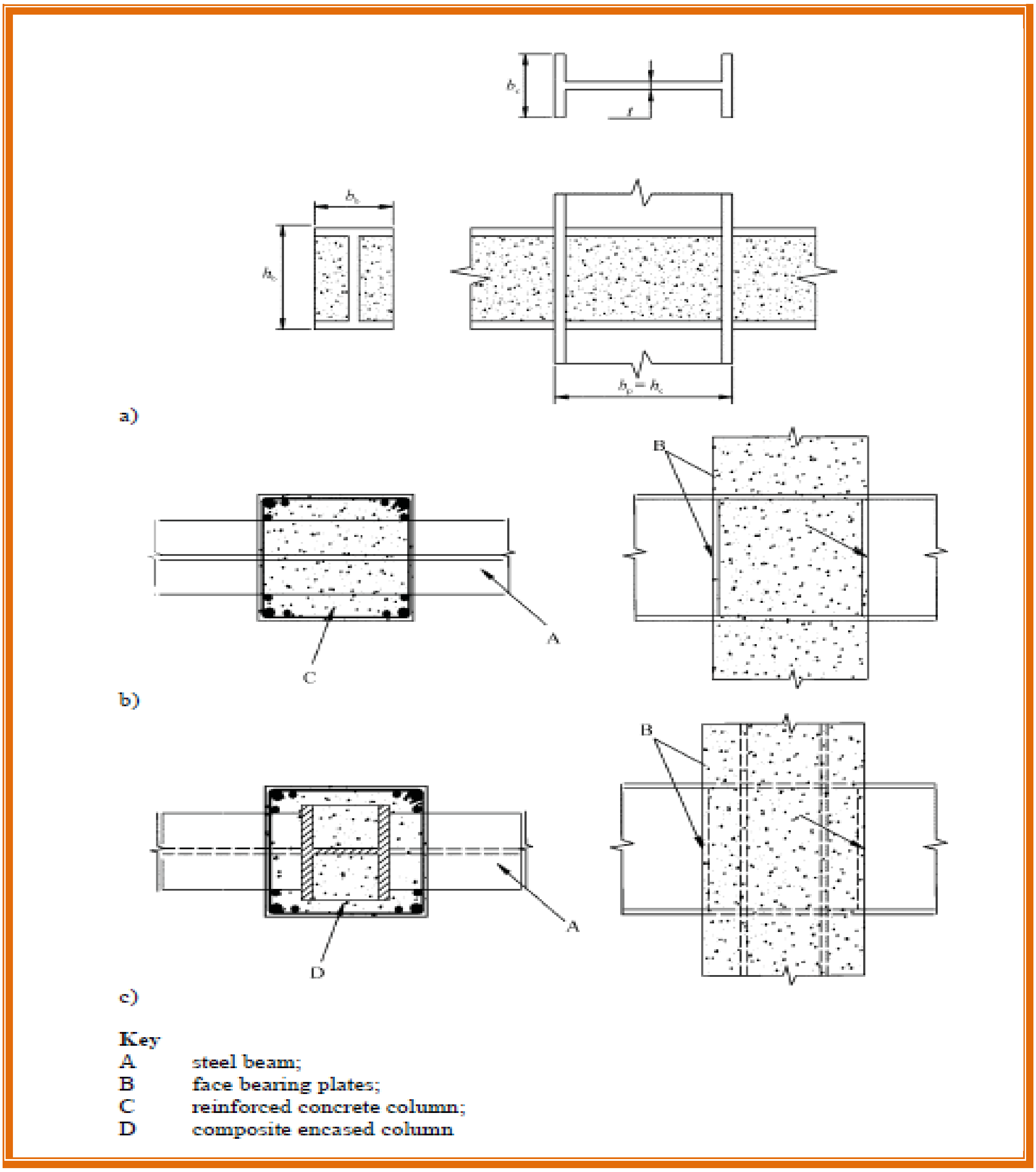


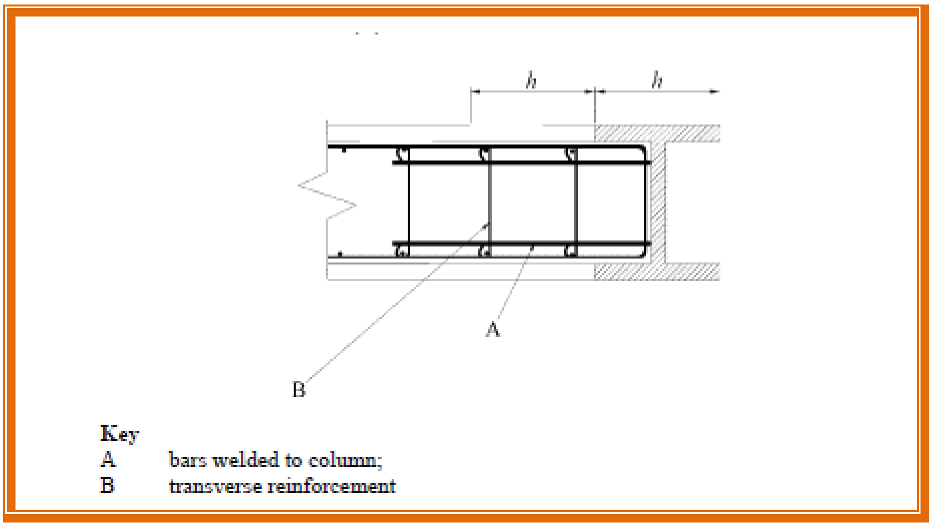
Fig (50-b) typical detail of eccentric bracing at the mid-span (Booth and Key, 2006)

5.7 Improvement of composite structural members

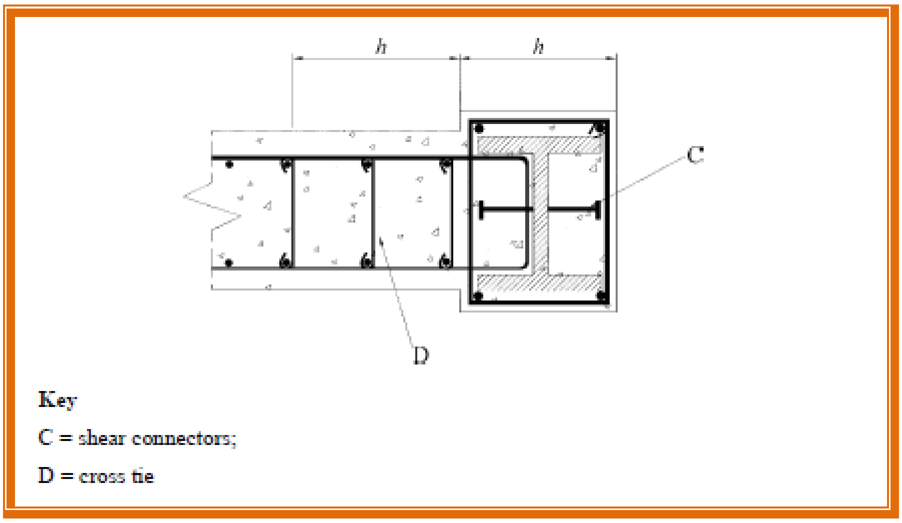
according to EN BS 1988-1-1 the following pictures illustrate the conceptual design members of composite structure



Fig(51) beam-column connection in composite structure imposed to earthquake according to (ENBS1998-1, 2004)



Fig(52) details partially encased composite boundary elements imposed to earthquake according to EN BS 1988-1-1



Fig(53) details of fully encased composite boundary elements imposed to earthquake according to EN BS 1988-1-1

CHAPTER SIX: REAL EARTHQUAKE FAILURES AND REASONS OF FAILURE

6.1 Global failure

6.1.1 Discontinuity of vertical elements (San Fernando- California-USA)

This failure can be seen from fig (54) in California indicates that failure in columns during earthquake due to interrupting vertical elements such as (shear wall). Resultant forces from diaphragm slabs and carried by vertical elements and transferred to the lower part of smaller column in stiffness in comparison with vertical wall. Therefore crushing failure resulted in the lower column.

Improvement measures:

(FIG(54) failure in column due to discontinuity in lateral resisting force San Fernando- California-USA) (Mahin, 1991)

6.1-2 soft story (Loma Prieta earthquake damage in San Francisco)

the picture shown that ground floor has considerably low stiffness and higher than those above it. This kind of failure arises from irregularity in vertical stiffness.

Fig (55) soft storey failure in Loma Prieta earthquake damage in San Francisco (Braile, 2003) and in Turkey (Polat Gulkan, 2002)

Improvement measures:

1- Adding extra column in between column however this measure may effect on function of that level.
2- Providing consistent stiffness throughout height of building. Lower column must be stiffest that those above it.
3- Constructing lateral resistant force system (shear walls) for example.
4- For existing buildings the column in the ground floor can increase their stiffness by coating technique. This technique is performed by putting more steel reinforcement around column and cast by concrete to obtain consistent stiffness.

6.1.3 Re-entrant corner configuration

The building in Aquila, Italy damaged by re-entrant corner. This came by complex L shape of the building. Which arise torsional and variation in rigidity problem this are results of out of plane of two part of building.

Fig (56) re-entrant corner failure in Aquila, Italy (albiani, 2012)

Improvement measurement

- ➢ Separation building into simple shapes by suitable gap as a seismic movement joint
- ➢ If the building is steel form, so the lateral braced system is adequate to protect
- ➢ Tying two part of building by collector wall(albiani, 2012, Arnold and Reitherman, 1982)

6.1.4 Weak column strong beam

Buildings are constructed supporting large diaphragm floor by weak column are exposure more likely to collapse than those have a strong column. The plastic hinge will move from beams towards column

Fig (57) weak column strong beam failure in Banda Aceh, Indonesia (Ahmed Ghobaraha, 2006) and in Pakistan (Yasir Irfan Badrashi, 2010)

Improvement measures

- Redesign building if the building have not implemented
- Arnold and Reitherman state that spendral-column separation in extranal lateral bracing can be built .

6.1.5 Pounding (Adjacency problem)

The first picture demonstrates two building in Maxico-city clashing during earthquake due to insufficient distance between two buildings.

Fig (58) pounding failure Maxico-city (Index)

Improvement measures

In designing two adjacent building the expected sway must be calculate by their natural period of vibration. The critical gap should be determined to avoid collapse (Reference)

6.2- Detailing failure

6.2.1 Poor detailing

Reinforced column carries combination of gravity load and vertical earthquake load, while longitudinal steel reinforcement compatibly with concrete cross section resist the vertical load. Transvers reinforcement (links) resist the lateral load in the form of shear force. The picture below shows the failure due to poor detailing of transverse reinforcement.

Fig (59) column failure due to poor detailing column (Heidi Faison, 2004)

Improvement measures:

- Reinforced concrete elements must be designed with compliance of Eurocode 1998. This is provided a full detail of reinforcement under seismic loading.
- Increase number of links throughout of the column

6.2.2 Out-of-plane Masonry wall (Aquila-Italy)

This happen if two orthogonal wall do not interfere completely. The in plane mechanism cannot develop during earthquake to act like box building. The picture shows the building damaged by earthquake in Italy due to lack of connection between walls

Fig (60) out-of plat failure (unipv, 2013)

Improvement measures:

- Provide tie beam regarding to the height of the building, this may help the integrity of walls together
- Provide steel reinforcement in the corner between foundation and slab
- Ratio of thickness to the height of the wall must be followed by codes and practice to increase stiffness of the wall to resist the shear force induced by earthquake.

6.2.3 Masonry infill wall.

The photo shows that infill walls damaged and partially collapsed by earthquake loading. This failure may refer to inadequate lateral supporting between frame elements and infill wall. The out of plane arise in the wall.

Fig (61) Masonry in filled failure (Earthquake Damage, 1990)

This can be improved by providing good condition of connection by means such as shear connectors.

6.3 steel failure

6.3.1 Plastic hinge failure in concrete beams:

This failure is common in reinforced concrete beams after deformations exceed plastic limit. The problem is resulted from inadequate amount of steel reinforcement particularly transverse reinforcement. This is also caused by lack of redundant lateral resisting force system. The photo was taken in Iran while heaviest beam in all floor collapsed by plastic hinge.

Fig (62) beam failure due to excessive plastic hinge occurrence (NOAA, 1990)

the problem can be improved before design this building by providing redundant lateral resistant force system or by more detailing steel reinforcement as well as providing bigger section with respect to size of column.

6.3.2 Steel connection failures:

Photo shows Local buckling of the bottom flange of 2-storey building in Japan by Miyaki-ken Oki earthquake. The second photo shows twisting of column by earthquake even the frame was moment resistant frame building.

Fig (64) beam failure due to excessive plastic hinge occurrence (James M. Ricles, 2011)

This problem can be avoided by design the steel building for both global and local buckling due to earthquake.

6.3.3 Fracture of welded joint:

This fracture happened due to excessive inter-story drift. The failure in second photo is uplifting the column out of base plate due to excessive inter-storey drift.

Fig (65) weld failure due to excessive inter-story (James M. Ricles, 2011) base plate detached due to excessive interstory drift (James M. Ricles, 2011)

This can be improved by installing stiffer column and reduce the mass of the floor.

6.3.4 Fracture of base plate due to overturning

The base plates in the photos below split into cap foundation by overturning moment.

Fig (66) overturning failure caused base plate rapture (James M. Ricles, 2011)

This problem can be avoided by designing greater base plate in dimension and thickness. Providing rigidity for base plate may reduce the effect of this overturning moment by resistant moment. Another approach is to install more anchorage bars to obtain well-connection between base-plate and foundation.

6.3.5 Fracture of braced frame connection

The first photo shows the buckling failure in the hollow section compression struts. However the second photo was caused by excessive. Both cases were resulted from inadequate section of the diagonal braced elements. Therefore it is important to design braced elements are able to resist earthquake forces.

Fig (67) bracing failure due to insufficient section (Clifton, 2011)   (James M. Ricles, 2011)

CHAPTER SEVEN: VULNERABILITY OF DOMESTIC CONSTRUCTION IN KURDISTAN AND METHOD OF THEIR IMPROVEMENT.

➢

Kurdistan is located medium seismicity location the epicentre lies in the middle of the Kurdistan region. Mousel is most intensively inhabitant (2 million inhabitants approximately) where just 30Km far from epicentre. The most recent earthquake event happened in 2010 damaged by 5.0degree of Richter scale.

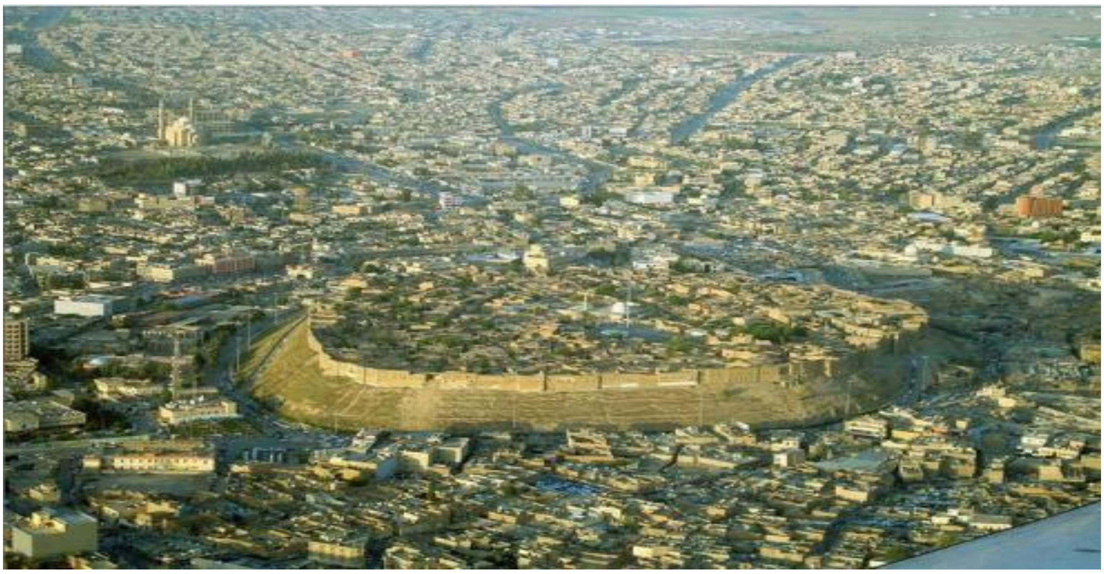
Mostly building in Kurdistan is unreinforced masonry or reinforced concrete building with infill masonry. This predominant of concrete and masonry reliance refers to sustainability and availability of cement manufactories resources in Kurdistan. Buildings n Kurdistan can be categorised into three types:

7.1 historical buildings

The capital of Kurdistan region is Erbil which full of different kind of building form, archaeological places such as citadel in the middle of city dates back to 400 B.C, minarets and gallery were constructed by earthen masonry. There are several historical house can be seen which are considered as a part of the history of that city also constructed by earthen masonry.

These building degrees of vulnerability to earthquake are extremely high. Cracks and failure can be seen in some of these historical walls. UNISCO with cooperation with government preserve these building complying standards and specification.

The method of their protecting from earthquake hazards is difficult without license of UNISCO. However these walls can be protected by external lateral support with changing its components.



http://www.iraq-businessnews.com/2010/12/06/3-2m-allocated-to-service-projects-in-erbil/

Courtyard of a building that burned.

http://roundthing.wordpress.com/category/places/erbil/

7.2 Residential buildings

Domestic house generally are unreinforced masonry comprise in single floor up to three floor levels. These house are unreinforced masonry comprise of bricks and mortar or concrete block and mortar. Generally are constructed on strip foundation. Floors are reinforced concrete mainly. Some sloped roof constructed by steel and wooden roof have been constructed in the mountain area due to abundant of falling snow.

Unit houses have been built without any seismic movement joints between two houses that is due to shortage of properties area. Therefore there is potential occur pounding between two buildings. The irregularity in the stiffness floor also account to weakness points of that building. For sloped floor which are constructed on the walls. These walls may prone to fails due to out of phase.

These residential building can be improved their performance by putting steel reinforcement between strip foundation and reinforced concrete slab. Additionally, in future, building must be separated by required gap according to mode of vibration of these buildings.


http://www.panoramio.com/photo/57307629

7.3 Low rise buildings:

Number of high rise building in Kurdistan is specific whereas majority of building are low rise building. These building are constructed by reinforced concrete frame and masonry concrete or brick infill.


http://www.panoramio.com/photo/59730377

http://www.skyscrapercity.com/showthread.php?t=1556016

Vulnerabilities to earthquake

1- Soft failure due to high of ground floor and weak floor by glass front ground level
2- Irregularity in stiffness
3- Re-entrant corner
4- Irregularity in mass. Water tank are installed at the top of floors
5- Most of building have only one shear wall placed in the corner of the building to accommodate lift and staircase

These risks can be improved by

1- proving consistency in stiffness of column throughout the building.

2- Designing building for earthquake and provide redundancy as an alternative load paths

3- Separating building onto more simple shape rather than being in contact.

4- Masonry mast be contact with frame steel reinforcement to prevent walls to spall in the frame during earthquake.

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