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# EARTHQUAKE RESISTANT DESIGN AND CONSTRUCTION PRACTICES IN JAMAICA, WEST INDIES

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## SUMMARY

**For a satisfactory performance against earthquake forces the structural response of a building to seismic loads must be less than the structural resistance of the building. This paper examines how this concept is interpreted in design and construction of buildings in Jamaica. The theory of having all elements and components tied together for better response is emphasised. Moment resisting frames shear wall and mixed frame/wall systems are examined for correct usage and effectiveness. Local practical interpretation of accepted seismic design codes of practice and standards are also examined.**

## INTRODUCTION

For a structure to perform satisfactorily, namely: Strength and stability
Resistance to earthquake and hurricane
Safety to users

it's development involves: The selection of suitable quality material
Determining how much of it is needed
Shaping it correctly
And placing it according to its behaviour when subjected to load.

The basis is appropriate structural design and detailing.

"Suitable quality" refers to strength and other essential properties like durability, stiffness etc.

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How much of it" (quantity) has to do with size of members to provide necessary stiffness, moment of resistance, moment of inertia etc.

"Correct Shape has connotations of comparison of shapes like square, rectangle, circle, triangle etc. With reference to the degree of inertia, moment of resistance, shear resistance (horizontal and vertical) etc. offered by each shape.

"Placing" refers to locating the right (quality and quantity) material where it is needed, where its use will be most effective i.e. where the material resists the right stresses eg. tensile steel reinforcement in the tension side of a reinforced concrete beam. The saying goes that "if you do not have the right material in sufficient quantity, appropriately shaped and correctly located (placed) you might as well live under a tree" because Gilbert Hurricane (Jamaica 1988) and Earth Quake will be much obliged.

In the Caribbean region building design for hazard mitigation is most critical. For a satisfactory structure design must consider the following: -

i) Planning of the structure (i.e. layout, member arrangement etc.)
ii) Materials, components and systems selection
iii) Standards, code of practice, specifications
iv) Design calculations- assessment of loads, moments etc.
v) Proper detailing and fabrication/construction

Planning refers to the layout and arrangement of all structural members to achieve necessary compactness, rigidity etc. Designer-subjective decision-making as to client need and poor implementation has often led to failure due to the omission of critical structural elements and features at the design stage. Appropriate framing has the most influence on the seismic performance of a building yet at the design stage when good engineering judgement is critical in the physical configuration of the building the engineer often has little say. The situation is not different in Jamaica.

**Materials, Components and Systems**

The building system is an amalgamation of raw materials and preformed elements/components. Thus a strong correlation exists between total system performance and performance of materials, elements and components. Selection is therefore critical.

**Standards, Codes of Practice, Specifications**

Standards are for quality control i.e. they exist to protect the public from "shoddy" goods. Lack of standards awareness and compliance creates the use of non-conforming, non-performing and sub-standard materials, products, processes and practices which can be suicidal in areas prone to natural hazards.

"A builder ordered 1000 cubic metres of sand for a job. On completion of the job he suspected that the sand had been extracted from the sea – a testing lab confirmed this. The lab asked the builder if the sand was to meet any standard specification. The answer was "No." "Then you got what you ordered" said the lab, "1000 cubic metres of sand". Quantity was specified, quality was not – an indication that full and accurate specification is critical.

System design, loading, fabrication and erection are generally governed by codes of practice and building regulations – compliance with at least minimum requirements is expected of engineers and architects.

**Design Calculations**

The resistance of the system to earthquake and hurricanes is governed by regulations requiring structural engineering training to accurately compute forces, bending moments, stresses etc. In Jamaica a good number of small to medium rise construction work often proceed without scrutiny by engineers, architects or other suitably qualified professionals. The quality of "design" could be suspect. Such approach to unengineered construction may save professional fees but lose the entire investment tomorrow if a turbulent hurricane or high magnitude earthquake hit. Fortunately this situation is changing with the introduction of professional registration and the enforcement of the regulation that all designs for proposed works be submitted for vetting by the appropriate planning authority and all plans must have a registered professional seal.

**Proper Structural Detailing**

Materials, elements and components must be located where they are needed (i.e. where the problem is) and in such ways as to provide effective (satisfactory) performance.

**Seismic Design – established practice in Jamaica**

General requirements

To safeguard the integrity and stiffness of a building under earthquake movement, the critical problem is to establish structural response provoked by the earthquake as an equivalent static seismic load causing the same deformation of the structure as the earthquake motion. Earthquakes generate vertical and horizontal vibrations in the structure causing displacements and deformations in the structural elements and the structural material. When deformations exceed their ultimate value the structure fails.

Thus the basic condition for structural safety is:

| | | |
|---|---|---|
| Structural Response | < | Structural Resistance |
| Actual Deformation | < | Ultimate Displacement |
| (due to structural response) | | (causing structural failure) |

The accepted method of establishing this structural response is to develop an equivalent static action i.e. a "seismic load" which when applied to the building will generate similar response. This is based on the SEAOC Code.

Base shear (seismic load), V = ZICKSW
Where Z = Zone factor, 0.75 for Jamaica
I = Important factor
1.5 for essential facilities – hospitals, fire stations, radio stations etc.
1.2 for large assembly buildings – theatres, schools etc.
1.0 for all other buildings – residential etc.

C = 1 (usually) $\quad C = \frac{1}{15\sqrt{T}} \quad$ where $T = \frac{0.05h}{\sqrt{D}}$

h = height above the base level
D = dimension of building in direction parallel to the applied forces.
T = fundamental elastic period of vibration (secs) in the direction under consideration
K= Structure type (factor selected from SEAOC code)
0.67 for ductile frames
1.0 for non ductile frames
1.33 for shear wall systems
S = soil factor (figure obtained from SEAOC code)
1.5 generally used in Jamacia
W= Total dead load of building, plus applicable portion of live load.
V = usually is between 0.094 W and 0.1 W

A "whiplash" lateral force Ft = 0.07TV is applied to the roof. The remaining lateral force (V -Ft) is distributed to intervening floors as follows (fig. 1).

Fx = Seismic load at level x

$$Fx = \frac{Wxhx}{\Sigma Wihi}(V-Ft)$$

Wx = dead load at level "x"
hx = height of level "x" above base
$\Sigma Wihi = W1h1 + W2h2 + W3h3 + \text{---} + Wnhn$

Masonry wall structures present a bearing wall system: -

i) with rigid reinforced concrete floor or roof slab as a horizontal diaphragm resisting lateral force (Fig. 2a)

- resisting walls behave as shear walls

ii) with a soft roof, lacking horizontal diaphragm action (Fig. 2b)

- walls behave as cantilevers fixed to foundation.

System (1) is more favourable for seismic areas. The slab combine with the shear walls to form a rigid box system – a very popular form of housing in Jamaica, particularly for low to middle income population. The required rigidity is obtained by tying wall steel into slab steel. Tie/belt beam along all structural walls provide perimetric reinforcement to slabs. Moment resisting slab reinforcement is anchored to the beam steel. Internal walls also interact as shear walls. Horizontal forces, including seismic loads, are transmitted to the shear walls, rigid in their planes. Strong earthquakes may cause mainly small deformations giving the structure, if properly designed, the chance of surviving the earthquake without cracks. Slabs may be insitu or precast. Insitu concrete with continuous reinforcement provides the greatest rigidity. With precast concrete the local practice is welding between steel plates embedded in the concrete.

Greater deformations occur in system (ii) owing to reduced rigidity along the top edge of walls. This underlines the critical work done by belt beams particularly where timber roofs sit on masonry walls (fig. 3). Belt beams confine all walls.

**Structural Detailing for Earthquake Resistance – Jamaican experience**

**Framing idealization**: The choice of framing system for any building is the structural engineer's function and partly the fait accompli presented by the architect. Three main systems are popular:

i) Moment resisting frame (Fig.4). Combination of beam and column frames in two directions. Beam moment capacity is less than that of adjacent columns.

ii) Shear wall systems (Fig. 5) Placed symetrically in building plan. Adequate number of walls aligned to resist shear in two directions.

iii) Frame – Wall systems (Fig. 6) Wall performing as a brace within a ductile frame. Wall and frame must combine as single unit, so wall/frame junctions are critical particularly where two different materials are used. Local practice has the block shear wall erected first and the reinforced concrete frame cast in. With the block wall and concrete keying into each other and the steel from wall tied into the beams and columns a successful combination is formed.

Foundations are usually inter connected to avoid relative horizontal displacement. Isolated column footings are normally together in ground beams (Fig. 4). These beams are normally designed to withstand compression or tension equal to the seismic load (base shear).

Walls: - Masonry walls use both vertical and horizontal reinforcement (Fig. 7) hence the use of hollow blocks. All pockets must be filled with concrete (cube strength 21N/mm$^2$ minimum).
Vertical steel (12mm) in all or alternate pockets depending on strength required. Horizontal reinforcement (10mm ) at every two courses helps to resist diagonal cracking (fig. 8). Reinforced concrete stiffeners/columns are placed at a maximum of 20 x wall thickness centres. Minimum wall thickness is 150mm.

Wall Openings – diagonal bars may be used at corners of door and window openings to resist fracture due to earthquake shock waves. Referred to as anti-crack bars, they are usually placed at 45° (fig. 9).

Columns (Fig. 10) Minimum dimension 300 mm (any direction) Columns are reinforced against repeated reversals of bending and shear stress.
Laps at mid height – minimum 30x bar diameter

Stirrups – 10mm steel minimum, maximum spacing 100 mm at column ends for distance

i) column dimension or,
ii) 1/6 of storey height or,
iii) 450 mm

whichever is greater

**standard spacing for rest of column**

Beams – treated similarly to columns (Fig. 11)

Proper confinement of concrete with closely spaced stirrups (75-150mm) for at least twice beam depth. Minimum dimension (150mm).

Beam-Column Connection

Proper confinement of concrete in both beam and column at this junction is critical. (Fig. 12) shows accepted practice of confinement for ductile moment resistance.

**Materials**

Concrete – For a ductile moment resisting frame a minimum cylinder strength of $21 N/mm^2$ (28day cube strength) is suggested. Same specification is advised for shear walls for minimum toughness in ductile behaviour. (In Jamaica concrete strength tests generally use cubes at 28 days rather than cylinder. An established conversions factor is

$$\frac{\text{150mm cubic strength}}{\text{150mm cylinder strength}} = 1.25$$

Seven day tests are also recommended as, though local cement meets the appropriate standards, erratic vibration or lack of vibration affects rate of strength gain. Poor strength concrete causes inadequate bonding to steel and cracks readily.

Reinforcing steel – either mild or high tensile steel is used. Steel is manufactured to the appropriate local standard (based on British and American standards). All imported steel is checked for compliance with regards to carbon content, bendability, yield strength etc.

**Conclusion**

Proper structural detailing and good constructional workmanship provide the best guarantees for good performance against earthquakes.

Select good quality material
Tie all elements together
Provide horizontal and vertical reinforcement in walls
Confine concrete in beams and columns near joints with close links.

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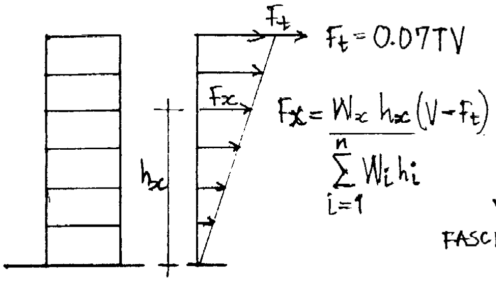



FIG. 1. Assumed Distribution – Lateral Forces

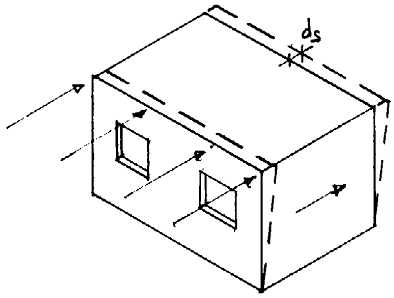



FIG. 2a. Building with hard roof. –rc slab

More rigid
Less deformation ($d_s$)

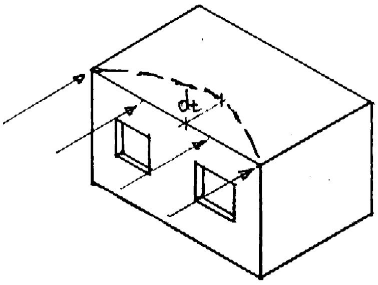
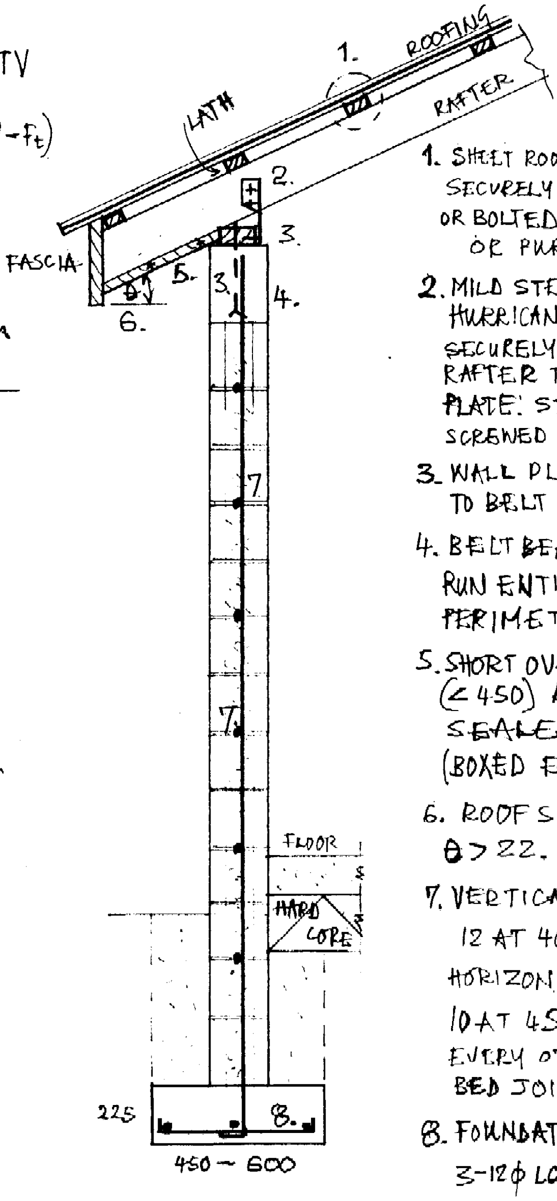



FIG. 2b. Building with soft roof. –timber roof

Less rigid
More deformation ($d_t$)




1. SHEET ROOFING – SECURELY SCREWED OR BOLTED TO LATHS OR PURLINS.
2. MILD STEEL HURRICANE STRAP SECURELY HOLDS RAFTER TO WALL PLATE: STRAP IS SCREWED TO PLATE.
3. WALL PLATE BOLTED TO BELT BEAM (4)
4. BELT BEAM TO RUN ENTIRE BUILDING PERIMETER.
5. SHORT OVERHANG (< 450) AND SEALED. (BOXED EAVE)
6. ROOF SLOPE $\theta > 22$.
7. VERTICAL STEEL 12 AT 400 c/c HORIZONTAL STEEL 10 AT 450 c/c ie EVERY OTHER BED JOINT.
8. FOUNDATION STEEL 3-12$\phi$ LONGITUDINAL 10 AT 225 c/c TRANSVERSE

FIG. 3.

EARTHQUAKE AND HURRICANE-RESISTANT CONSTRUCTION

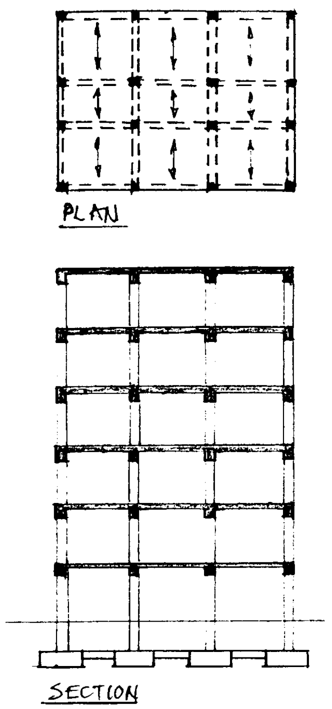



FIG. 4. MOMENT-RESISTING FRAME

Beams in both directions.
No rigid wall elements.
Tied foundations.

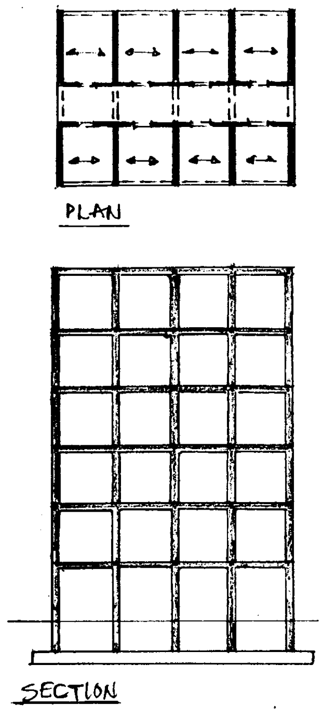



FIG. 5. SHEAR WALL SYSTEM

Central beam coupling.
Shear walls in both directions.
Continuous foundation.

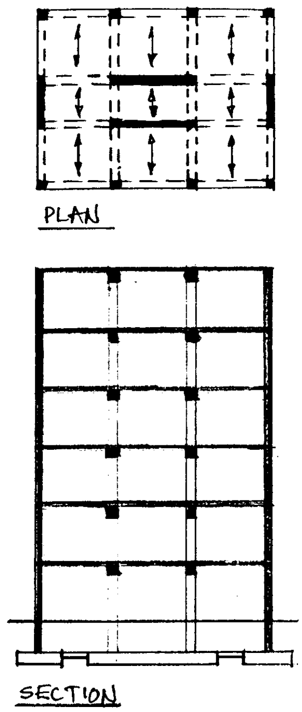



FIG. 6. FRAME-WALL SYSTEM

Beams in both directions.
Random shear walls.
Tied foundations.

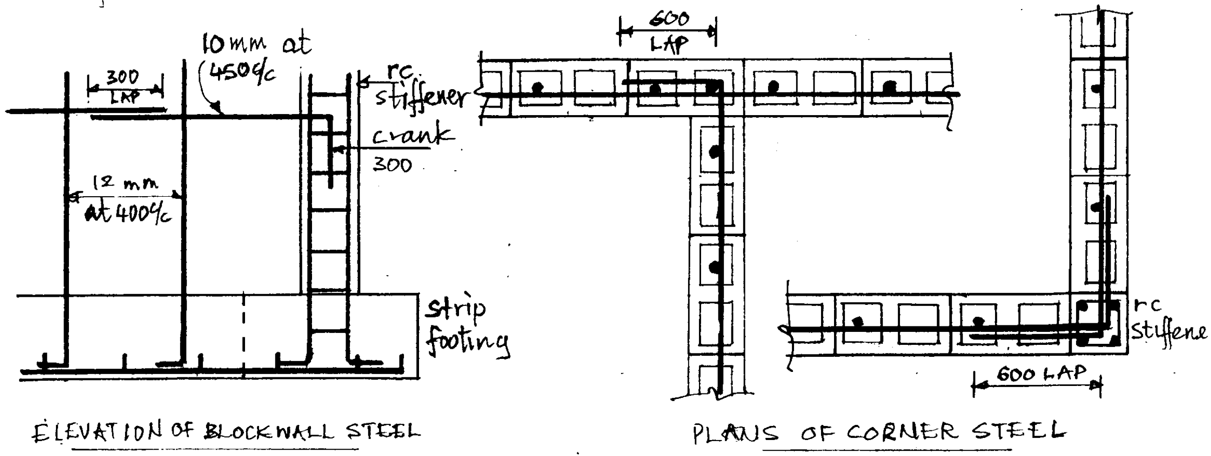



FIG. 7 MASONRY WALL CONSTRUCTION

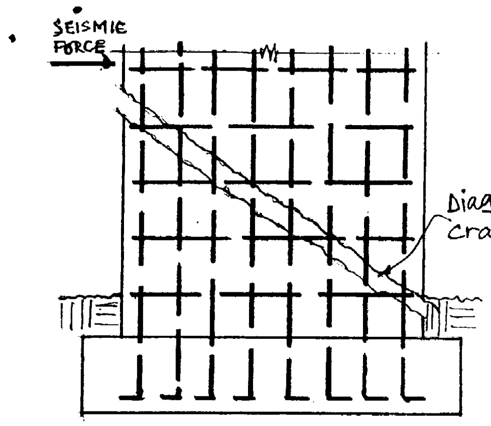



FIG. 8. HORIZONTAL STEEL RESISTS CRACK

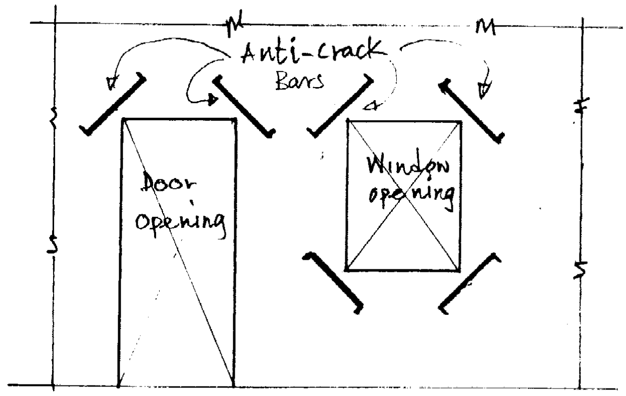



FIG. 9. DIAGONAL ANTI-CRACK STEEL AT CORNERS OF DOOR & WINDOW OPENINGS

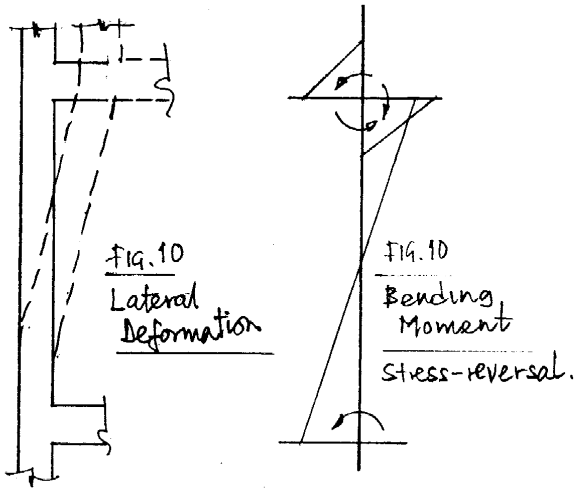


FIG. 10 Lateral Deformation

FIG. 10 Bending Moment
Stess-reversal.

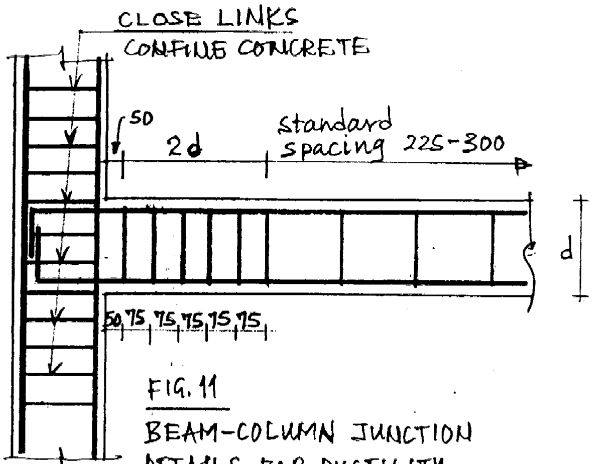



FIG. 11
BEAM-COLUMN JUNCTION DETAILS FOR DUCTILITY

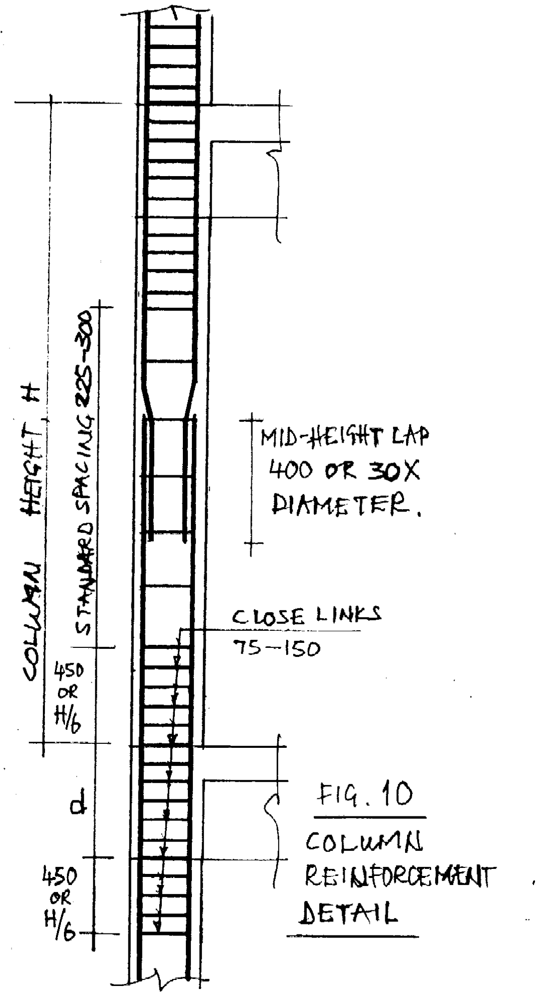



FIG. 10
COLUMN REINFORCEMENT DETAIL

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