LARGE HOSPITAL BUILDING CONSTRUCTED IN RECORD TIME

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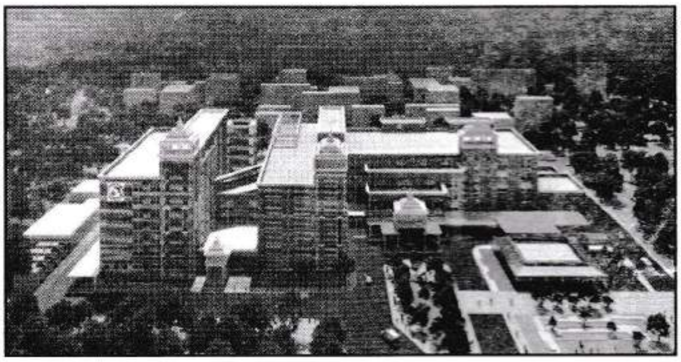


1.0 Introduction

Alamelu Charitable Foundation (an initiative of Tata Trust) plans to construct Cancer Care Hospitals at various locations in India. One such hospital Mahamana Pandit Madan Mohan Malaviya Cancer Centre (MPMMCC) was recently completed at BHU Varanasi in a record time of 10 months for the construction of about 5,80,000 sq. ft. built up area. This article describes salient features of structural design of this building.

2.0 Details of the Building

The building consists of three wings called IPD, DNT and RT.

IPD Wing has a Basement + Ground Floor + Seven Upper Floors + Terrace.

DNT Wing has a Basement + Ground Floor + Five Upper Floors + Terrace.

The two wings (IPD & DNT) are continuous on lower floors but are separated above first floor but connected by a bridge at fourth and fifth floor levels. These two buildings house OPD and various other departments on various floors.

The third wing called RT is of Ground + Four Upper Floors + Terrace. Its lower two floors also house Linac – which have very thick RCC slabs and walls.

The floor finish was generally of ceramic tiling and the internal walls were of light weight Siporex blocks. In some areas housing CT scan and MRI machines, 150 thick RCC walls were required to be provided.

The total construction area including basements is about 5,80,000 sq. ft. The clients required that construction of the buildings be completed within a period of 10-12 months.

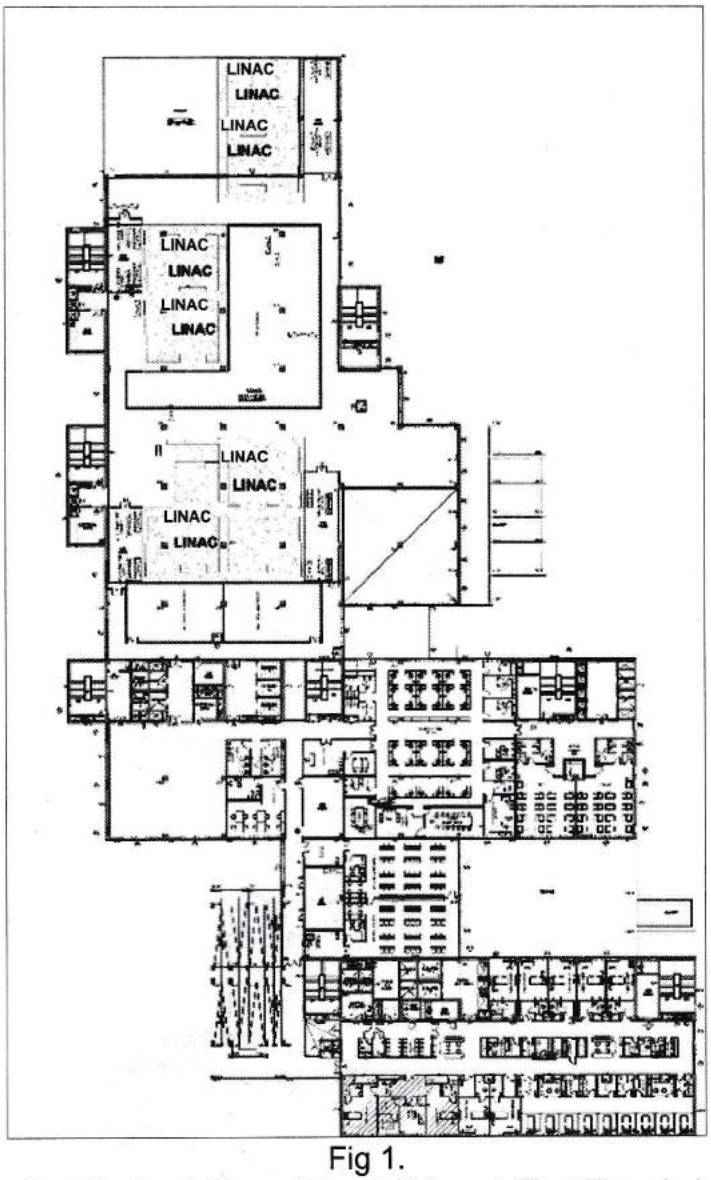


Fig 1.
Architectural Plan of the Building at First Floor Lvl.

3.0 NDMA Guidelines for Structural Design of Hospital Buildings.

The hospital building was required to be designed following "National Disaster Management Guidelines" issued by National Disaster Management Authority (NDMA)[1] besides following the relevant IS codes. NDMA guidelines are much more severe than specifications of IS codes especially for EQ loadings, the reason apparently being that under a very severe EQ even if other buildings have failed the hospitals have to be functional to treat the casualties of the disaster and hence should be designed much more conservatively than other buildings.

NDMA recommendations on the structural design of hospital buildingsprohibit many types of construction such as flat slab floors, floating columns, prestressed floor systems, precast construction etc. The lateral forces due to EQ are specified as:

$$V_b = A_h W$$

where $A_h = \frac{Z.I}{R}\left[\frac{Sa}{g}\right]$ and V_b= Base shear

The formula for A_h above is similar to that in clause 6.4.2 of IS 1893 (Part 1:2016) [2] except that the factor 2 in the denominator in the IS code formula is absent in the above formula. This means that as per NDMA guidelines the building has to be designed for two times the earthquake forces than those obtained for the same building by IS 1893. In addition, with importance factor I=1.5, the lateral earthquake forces for the hospital building become three times those of a similar residential or commercial building.

NDMA also specifies that"The total cross-sectional area of all RC Structural Walls shall be at least 4% of the plinth area of the building (if that based on design is smaller than 4%), along each of the two mutually perpendicular principal plan directions".

This clause seems to be unreasonable considering that as per this clause:

a. In the same earthquake zoneif there are two buildings of different heights, say,one of 10 stories and the other of 20 stories with about the same floor/plinth area, then still for both the buildings the same areas of shear walls haveto be provided = 4% of plinth area although in the second building stresses due to EQ loads will be much higher.

b. If there are two buildings which are very similar in height and plinth area but in two different EQ zones, still for both the buildings minimum shear wall area will have to be the same.

In our opinion this clause in NDMA needs to be amended. We were told by a member of the NDMA committee that they are giving such requirements based on some studies of buildings in EQ Zone IV and then specify them as a general requirement for buildings in any zone. This needs to be changed in amended guidelines.

4.0 Structural Scheme

The columns were placed on a grid of about8.5 x8.5m as per architectural requirement. Flat slabs are not permissible and hence a structural arrangement with R.C.C. slab and beam structure with RCC columns and shear walls was possible. However, considering the stringent time constraint for completion of the building, it was decided to design the main structural elements in structural steel to facilitate speedy construction although it would mean a higher cost compared to a normal RCC structure.

Thus, the floors were designed as RCC slab supported on metal deck and steel beams which spanned between steel columns. The thickness of slab was150mm (90mm flange + 60mm ribs). The secondary steel beams were mainly built up I sections of 460mm depth supported on main beams which varied in sizes but were generally built up I sections of 600mm depth. Some beams were also of lesser or more depths. The slab and beams were connected by steel studs to make them act as composite sections.

The columns were generally built up I sections of 400mm depth and 450 wide flanges. On higher floors the sizes were reduced. They were encased in concrete with steel reinforcement and were designed as composite columns

The RT wing the area housing Linac had walls and slabs more than 1m thick to control radiations,

For lateral load resistance steel diagonal braces inside the building or on its façade were not possible architecturally. Hence, for lateral load resistance shear walls were provided and also many of the main beams were connected to steel columns with moment connections. Thus, the lateral load resisting system consisted of shear walls with steel moment resisting frames. Even though IS code specifies R=5 for a dual system consisting of shear walls + moment frames, R=4 was considered conservatively as it was difficult to design the steel frames to resist minimum 25% of the base shear, considering that lateral forces due to EQ were much too high for this building using NDMA guidelines and importance factor of 1.5.

The concrete grade was M30 for deck slab and M40 for other members. Reinforcement was with Fy = 500N/mm^2. Structural Steel was with Fy = 350 N/mm^2 and for some members even steel with Fy = 450N/mm^2 was used.

The structural layout of the second floor is shown in Fig. 2.

Analysis of the whole structure was done using Etabs software.

The soil report showed that raft foundation with a SBC = 24.5T/m^{2}could be used. Hence, the foundations were designed as a 1200mm thick raft in IPD/DNT building and 1000mm thick raft in RT building. Rafts were analyzed with SAFE software considering soil as springs with stiffness corresponding to modulus of sub grade reaction. The water table level at the site was much below the ground level and hence there was no difficulty in carrying out the construction of foundation and retaining walls with open excavation.

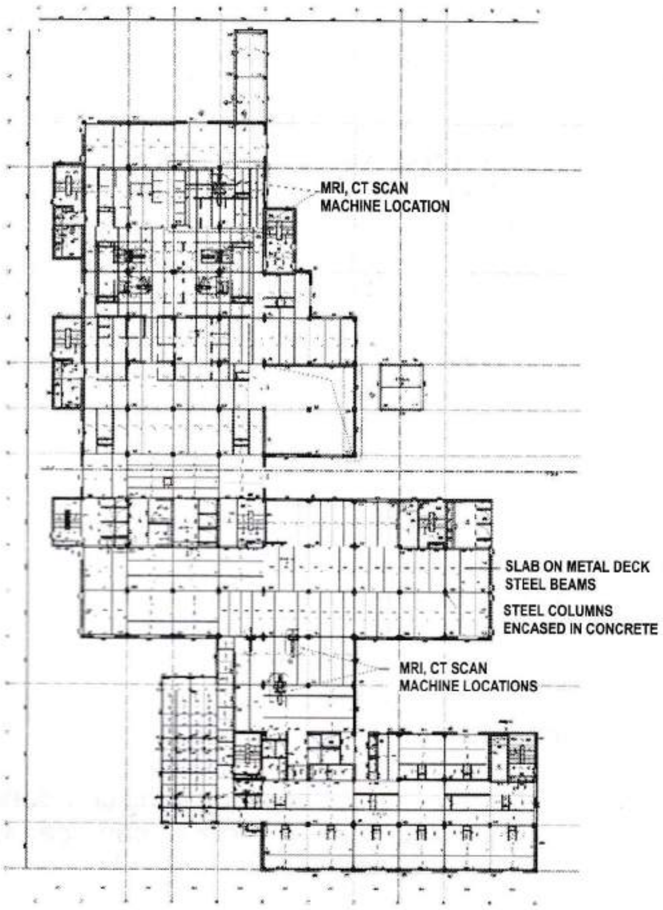


Fig. 2.
Structural Layout of the Second Floor Lvl.

For fire resistance the internal steel beams were covered with vermiculite. The beams of facades were encased in concrete.

5.0 Control of Vibrations

5.1 Floors consisting of long span steel beams can lead to uncomfortable vibrations excited due to human activities on the floor such as walking within the rooms or in adjoining corridors. Indeed, such vibrations can be experienced on airport or mall floors with long span steel beams and on foot bridges. Considering that frequency of the forcing function due to human movement is generally between 1.5 to 2.5 Hz it was checked during the design stage that the fundamental frequencies of vibrations of the floors were higher than 3Hz.

However, **after most of the structure was constructed** we were given the limits on velocities and accelerations to be controlled in some bays on the second floor where MRI and CT scan machines were to be installed. The limits were specified by the vendors GE Health supplying the machines.

Hence, further study was done using AISC (American Institute of Steel Construction) Design Guide Services article "Floor Vibrations Due to Human Activity" [4]. The Concrete Society Publication [5] also gives guidelines for calculating footfall induced vibrations.

Operations of a sensitive machine can be affected due to floor vibrations caused by persons walking in the room where the machine is located or in adjoining corridors. Also, vibrations of floors can cause discomfort to persons working in the area.

Natural frequencies of the floor and the resulting vibrations will vary with the actual loads present.Hence,realistic values of SDL = 3KN/m^2 and L.L. = 0.5KN/m^2 (+ machine loads) in the bays where machines were to be located were considered to obtain the natural frequencies of the floor – although design loads were of higher values.

5.2 Vibrations for Human Comfort

i. As per AISC Design Guide [4], for human comfort the peak acceleration when a person of weight 70kg.(157 lbs) is walking should be less than 0.5%g.

The Concrete Society Publication [5] and ISO 2631-2, 1989 give threshold values of RMS accelerations for human perception. AISC guide considers peak accelerations as multiple of RMS values. The multiplying factor varies for residences, malls or footbridges etc. and is taken as 10 for residential and office areas.

ii. For consideration of human comfort, values of peak acceleration due to a person walking are calculated at the center of a bay.

As per AISC guide peak acceleration due to walking can be estimated by the formula

$$\frac{a_p}{g} = \frac{P_o e(-0.35fn)}{\beta W}$$

Where a_p = estimated peak acceleration,
g = gravity acceleration,
f_n = natural frequency of the floor structure,
β = damping ratio. Damping associated with floor systems is recommended = 0.03 for floors with small demountable partitions as in typical modular offices and = 0.05 for floors with full height partitions between floors,
P_o = a constant force = 0.29 KN for floors and 0.41KN for bridges, for a person of 70 Kg weight walking on the floor,
W = Effective weight of the floor (in the area under consideration).

In the present case, there are walls of full floor height and hence damping was considered = 0.05. Value of floor frequency was obtained from ETABS analysis which gives different values for different mode shapes of floor structure. The value which shows a fundamental mode in the bay under consideration was used as f_n. The peak accelerations thus obtained were within limits.

Since the floors were already constructed (although without partition walls etc.) few tests were done at site by having persons walk at different speeds on the floor and check if any uncomfortable vibrations were felt by other persons. No such uncomfortable vibrations were felt.

5.3 Vibrations for Smooth Operation of Sensitive Machines

Machines like CT scan and MRI are very sensitive and give improper images if subjected to vibrations from floor. It is desirable that they are placed on the ground floor (without basement). But in the present building they were located on the second floor.

As per AISC guidelines [4]:

i. The values of acceleration and velocities on the floor are considered due to a person weighing 84kg walking at a) fast pace (100 steps/min.), b) moderate pace (75 steps/min.) and c) slow pace (50 steps/min.),

ii. For movement of persons within the room where a sensitive machine is located, the walking speed will be that of slow pace. Only in any corridors near the locations of the machines the walking speed could be considered as fast, as per AISC.

AISC Guide gives criteria for limiting vibration velocity for different types of equipment such as Computer Systems, Bench Microscopes, Microsurgery Equipment, Electron Microscopes etc. The vendor in the present hospital had given the limitations for smooth operation of the CT scan, MRI machines as:

max. acceleration = 25mm/sec^2= 0.025g (as against 0.5g for human comfort) and max. velocity = 40mm/sec (micrometer / sec) which was similar to that given for Bench microscopes, optical and other precision balances etc. in AISC guide.

AISC Guide gives max. displacement as

$$X_{max} = \frac{Fm\Delta p}{2} \left(\frac{fo^2}{fn^2}\right)$$

Where F_m is a footfall impulse parameter taken as 1.4, 1.25 and 1.1 KN respectively for fast, moderate and slow walking conditions for a walking person of 84 kg weight. Corresponding f_o values are given in AISC guide as 5.0, 2.5 and 1.4 Hz respectively.

Δ_p is the deflection of the structure at the location of the machine under a unit load which were obtained from analysis of the floor structure. After calculating X_{max} from above, max. velocity V max and max acceleration a_p are obtained by the relations:

$$Vmax = 2(\Pi)f_n X_{max}$$
$$ap = 4(\Pi)^2 f_n X_{max}$$

Using the above equations, it was found that under slow walking condition the acceleration and velocity were within allowable limits. But there were long corridors adjoining various rooms in which the machines were to be placed. Hence, vibrations due to brisk walking of persons in the long corridors had to be considered.

It was found that for brisk walking of persons in the corridors, the maximum velocity and accelerations were beyond the specified limits.

5.4 Remedial Action

To reduce vibrations of a floor, AISC guide also suggests remedial measures such as stiffening of steel beams by adding cover plates at bottom or adding below it queen post type truss members, addition of columns etc.

In the present case the following changes were made:

i) The locations of the machines (not yet installed)were shifted to be on stiffer main girders and as close to columns as possible instead of in the center of bays. This reduces values of Δ_p in the above equation and hence X_{max}. The architects changed the room plans accordingly.

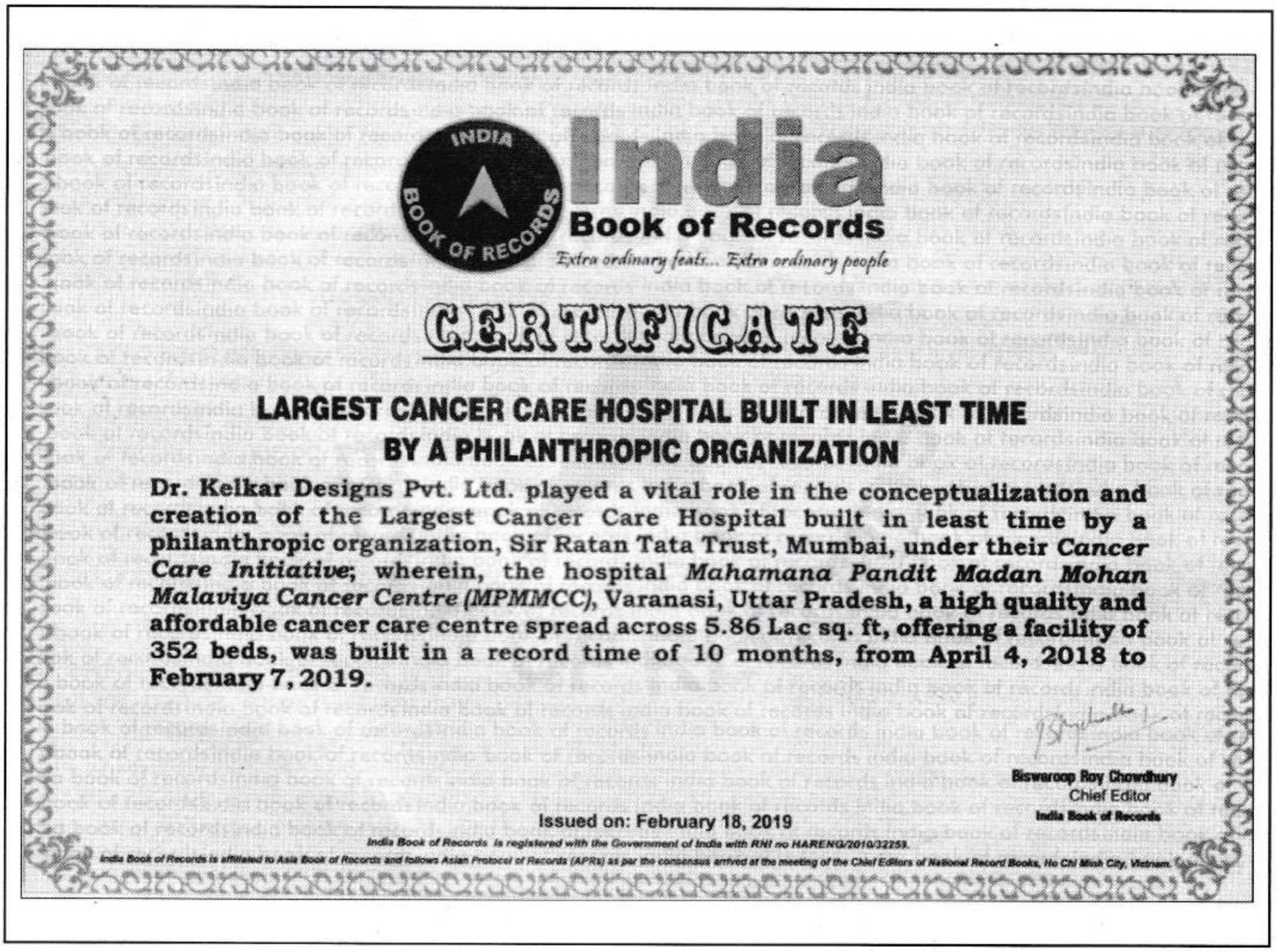
ii) In addition, A type steel bracings were proposed below the girders supporting the machines so as to minimize value of Δ_p to almost zero in the above equation thereby reducing V_{max} and a_p. Since the floor below was a service floor, provision of bracings was possible.

iii) For minimizing brisk walking in the corridors AISC Guide also recommends creating obstacles such as reception tables etc. in the corridors to reduce brisk walking. But this was not practical in the present case and hence not done.

After these changes it is expected that the machineswhen installed will operate smoothly as desired.

It was, however,not possible to check vibrations of the floors in the areas of the machines due to operation of hospital power plants, ac units, pumps/motors, elevators etc.

6.0 The construction of the building was started with excavation for foundations in the first week of April 2018 and completed by end of Feb 2019. It was inaugurated by P.M. Narendra Modi on 19.02.2019. The total design and construction time was unusually small for construction of a building with such large area.



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CERTIFICATE

LARGEST CANCER CARE HOSPITAL BUILT IN LEAST TIME
BY A PHILANTHROPIC ORGANIZATION

Dr. Kelkar Designs Pvt. Ltd. played a vital role in the conceptualization and creation of the Largest Cancer Care Hospital built in least time by a philanthropic organization, Sir Ratan Tata Trust, Mumbai, under their *Cancer Care Initiative*; wherein, the hospital *Mahamana Pandit Madan Mohan Malaviya Cancer Centre (MPMMCC)*, Varanasi, Uttar Pradesh, a high quality and affordable cancer care centre spread across 5.86 Lac sq. ft, offering a facility of 352 beds, was built in a record time of 10 months, from April 4, 2018 to February 7, 2019.

Biswaroop Roy Chowdhury
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Main Contractor : Capacite Infraprojects Ltd.
Structural Steel Fabrication, Design and Erection : JSW Severfield Structures Ltd.

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