AE SENIOR THESIS 2012-13

TECHNICAL REPORT 2

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The Optimus

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Executive Summary

The purpose of the report is to analyze and perform a pro-con study of the existing and alternative floor systems. This is achieved by doing a preliminary design of three alternative floor systems. The design is performed using loads common to a typical 27.6‘x27.6’ bay on a typical office floor. The 4 floor systems compared are:-

1. Flat slab with drop panels (existing)
2. Composite system
3. Steel decking with joists
4. Precast Double Tee

The 8” flat slab system with 4’6 x 4’6 drop panels is one of the top viable choices because it is cheaper and fits best with the construction methods in India. It also gives a higher desirable floor to ceiling height. However, one of the drawbacks is that its is the heaviest of the four systems. This system was checked for short and long term deflections and seem to conform with ACI Specifications.

A composite system is also equally a top viable choice among the three alternative systems. A 3” 3VLI concrete deck topped with 4.5” concrete on a W10x22 wide flange beam forms a fully composite section that sits on a fully composite W18x55 girder gives a depth that is slightly high as comparable to the flat slab. The system is lighter and is cheaper from the scenario of construction in US. However, this would get expensive if constructed in India. However, the slight higher price gives an efficient system over a flat slab.

The fastest to construct precast system was designed using service loads and using the Precast Concrete Institute Handbook. A double tee prestressed concrete slab that has 10’ wide flange and is 24” deep is a lighter but expensive choice over a flat slab system. Also, it gives a high depth which decreases floor to ceiling height.

The 3” 3C18 metal deck with 3” concrete topping on 24” joist is the least viable choice because it is expensive and gives a much high depth which is not architecturally acceptable. However, one of the great advantages of steel decking is that it is lighter resulting in a lighter building.

Building Introduction

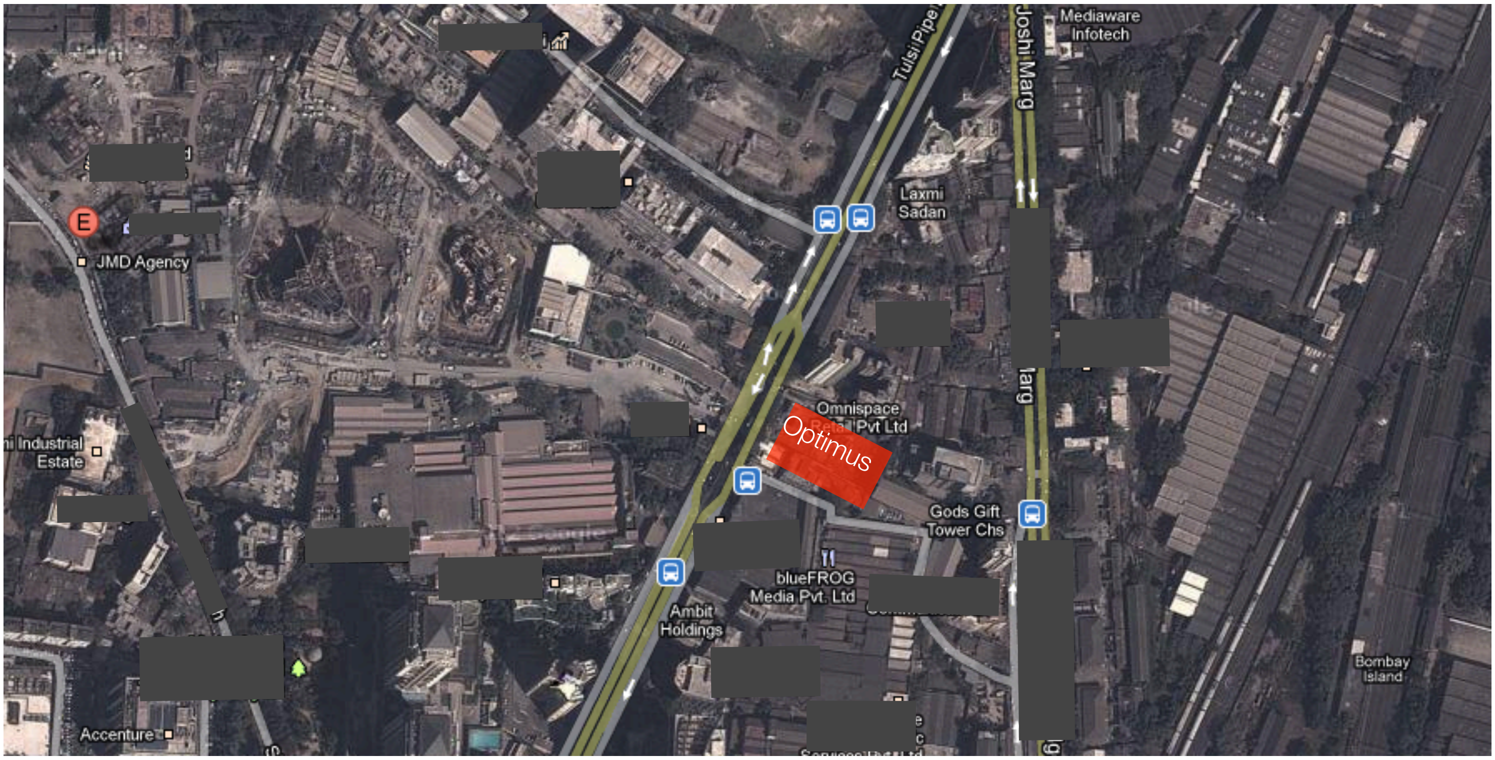


Figure 1 Aerial map from Google.com showing the location of the building site.

The Optimus, is a new building coming up in the city of Bombay, the economic capital of India. In a city that thrives on all kinds of businesses from small scale to large corporate companies, The Optimus will be catering medium size companies to set up their offices close to the business district of the city. The location is highly mixed use, as it contains residential towers, large shopping malls, office buildings and factories. While the future of the location is going to be marked by tall skyscrapers soaring about 100 stories, The Optimus is designed to provide a much humble yet modern look to fit in the fabric of the city.


Figure 2 Rendering showing roof garden

The design of The Optimus in the interior and exterior is very functional as well as aesthetic. It makes an efficient use of space within tight boundaries of the site and provides spacious floor space to its inhabitants. To cater the requirements of the offices, it offers open and customizable floor space. The spacing of the structural and architectural elements offers flexible partitioning for office spaces. The building provides recreational facilities that include a gymnasium, roof garden, green balcony spaces at every floor and a garden at the lobby area. The 2 basements and first 3 levels are dedicated to parking with 5 level as garden, lobby and office. The office spaces start from 6 to 16^{th} story and 17^{th} story contains a roof garden.


Figure 3 Rendering of the building entrance

Just as the interior, the exterior of the building is efficient in utilizing the available resources at the same time maintaining its aesthetic qualities. The envelope of the building designed to fit the location which also becomes an architectural feature of the building. Three kinds of materials decorate the facade: metal, stone and plants. As the north facade of the building faces a tall residential tower, all the office space is moved to the south facade and giving a better view of stone and green wall to the residents of the adjacent tower. The south facade is dominated by a bold and modern look with metal cladding and windows pushed inside to provide solar shading in the interior. The front facade that faces the main street shows a play of all materials on the facade: stone, metal and green wall giving a rich look to the building front.

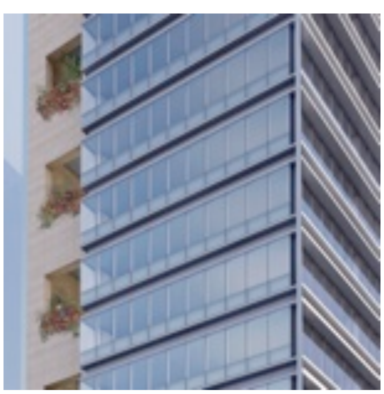


Figure 4 Rendering of the building facade

The structure of the building is something that complements the architectural beauty. A successful building is achieved when its structure and architecture integrate without compromise, and this applies to The Optimus. In order to provide the celebration of facade, open floor plan and efficient floor area, the structure plays a very significant role. All the columns in the floor area are pushed to the exterior so that interior is open and at the same time no column is visible in the exterior to provide different architectural features on the facade. In this way the structural system of building does not compromise the architecture but celebrates it.

Structural System Overview

The structural systems of The Optimus has been optimized to increase floor space area, to celebrate the architecture and decrease the overall cost of the building without compromising safety. In order to achieve these goals, concrete was chosen as a prime material to support the building. The properties of concrete allows fluidity in design, room for design changes during construction and makes the construction process cheaper by employing the ample of labour force available at a cheaper cost. All the structural systems from foundation to slabs come together to improve efficiency in design and safety.

Foundations

The geotechnical investigation report was performed by Shekhar Vaishampayan Geotechnical Consultants Pvt. Ltd. and special care was taken to avoid disturbances to adjacent buildings as the site is tightly surrounded by factories and residential buildings. As the building has two basement floors, the geotechnical investigation included excavation qualities of the site. Besides excavation, the soils report consists of soil bearing capacity of the soil, water table information, properties of soils and rocks at different levels below ground.

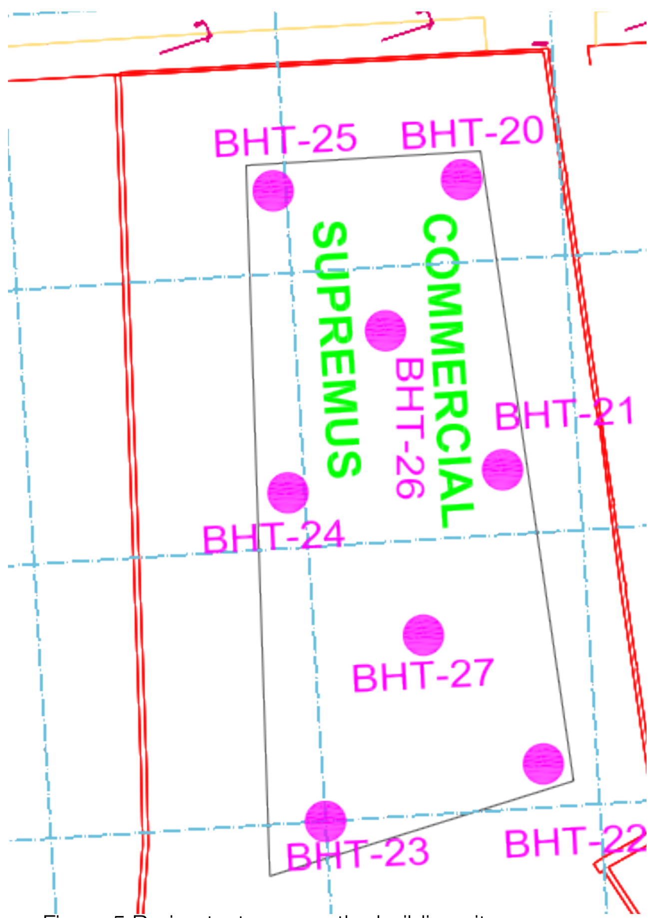


Figure 5 Boring test map on the building site.

8 boreholes were drilled and soil properties were analyzed in a lab. It was discovered that soil properties consisted of filled up soil, medium to stiff clay, weathered rock and highly to slightly weathered tuff. The minimum depth of excavation was determined to be 12.5 m / 41 feet below ground level. The basement raft was decided to be placed 10 m / 33 ft below ground level. The soils report explained that the soil and clay below ground would exert lateral pressures on the basement walls. To account for these lateral pressures, the reinforced concrete frame and the main structure of the building will internally support the basement

walls. Therefore, the basement walls were designed for hydrostatic pressure as well as the earth pressure. The ground water table was determined to be present at a depth of 1.00 m / 3.3 ft below ground. This was a conservative figure chosen by the geotechnical consultant to account for the built of water pressures during heavy monsoon season in the city.

Gravity Framing System

The reinforced concrete framing system of The Optimus is developed to fit the different types of floor spaces from the basement to top floor. The column, beam and slab system is chosen to fit with the architecture of the building as well as to act as an architectural element.

Architecture and structural system integration is seen in the columns of the building that change its cross sectional properties and layout as the space progresses from basement to the top of the building. The columns from the basement to the level 5 are rectangular and oriented parallel to the parking spaces. These rectangular columns transition to circular and square columns in office spaces from level 5 to the top level. This transition is occurs with the use of transfer girders, columns brackets and adjustments to account for eccentricity in the columns. The columns sizes range from 1.5 ft to 3 ft in the weak axis and 1.5 ft to 7 ft in the strong axis direction. Circular columns range from 1.5 ft to 3 ft in diameter in the office areas. the building has a peculiar column with cross section of a parallelogram. This column is located at the entrance of the building and defines the corner of the building from the base to the top adding to the architecture.

The columns are tied together with beams, girders and mainly the flat slab system of the floor framing. The 8 - 12 in slabs connect to the columns with drop panels ranging about 2 in additional depth. Drop panels mainly exist at parking spaces and thin drops are added at slabs in office spaces. The slabs also create interaction between the columns and core walls of the building and help distributing gravity loads.

Lateral System

The wind and seismic forces are handled by the extensive shear walls that exist around the stairwells and elevator core. These reinforced concrete shear walls range from 8 in to 20 in thickness are designed to resist lateral and torsional forces due to wind and seismic loads. These walls span from basement to the top of the building and are connected using link beams. In N-S direction of the building, the shear wall and to some point the strong axis of the columns help in resisting the lateral forces. This is because width of the building is small in the N-S direction and strong axis of columns provide support to the shear walls through the connection with the slab. In the long side of the building i.e. the E-W direction the long and strong axis of the shear walls seem adequate to control drifts and resist forces in the E-W direction.

Design Codes

As the building is located in India, the Indian Standard (IS) code is used to design The Optimus. However, in this report the American codes are used for checks and analysis. This will provide a comparison between the two codes and also a look into the design from the perspective of the american rules.

- Minimum design loads for Buildings other than seismic loads

IS Code	Description
IS 875 (Part 1): 1987	Dead loads
IS 875 (Part 2): 1987	Imposed loads
IS 875 (Part 3): 1987	Wind loads
IS 875 (Part 5): 1987	Special loads and load combinations

- Seismic Provisions for buildings

IS Code	Description
IS 1893: 2002	Criteria for earthquake resistance design of structure
IS 4326: 1993	Earthquake resistant design and Construction of Buildings - Code of Practice
IS 13920: 1993	Ductile Detailing of Reinforced concrete Structures subjected for Seismic Forces - Code of Practice

- Building code requirements for Structural Concrete:

IS Code	Description
IS 456: 2000	Plain and Reinforced Concrete - Code of practice
SP 16	Structural use of concrete. Design charts for singly reinforced beams, doubly reinforced beams and columns.
SP 34	Handbook on Concrete Reinforcement & Detailing
IS 1904	Indian Standard Code of practice for design and construction foundations in Soil: General Requirements

IS Code	Description
IS 2950	Indian Standard Code of Practice for Design and Construction of Raft Foundation (Part –1)
IS 2974	Code of practice for design & construction of machine foundation
IS 2911	Code of practice for design & construction of Pile foundation (Part I 1o IV)

- Building code used for Structural Steel

IS Code	Description
IS 800: 1984	Code of practice for general construction in Steel

- Design codes to be used for Tech 1

American codes to analyze the existing conditions.

American Code	Description
ACI 318-11	Concrete Design Code
ASCE 7-10	Minimum design loads for Buildings and Structures for Dead, Live, Wind and Seismic loads.

Materials

Materials used on this project help achieve efficiency in the structural system. In vertical structural the strength of the materials increases as the required strength of the member increases. This helps in improving efficiency by increasing material strength instead of increasing the size of the member.

Use of the material	Indian Code	American Code
	Material	Equivalent Material
Raft and pile foundations	M40	5000 psi
PCC	M15	3000 psi
slabs and beams	M40	5000 psi
Perimeter basement wall except Grid A	M40	5000 psi
Perimeter basement wall on Grid A	M60	7000 psi
Walls, Columns and Link beams from foundation for 5th floor	M60	7000 psi
Walls, Columns and Link beams from 5th floor to above	M40	5000 psi

<table>
<tr><th colspan="6">Concrete</th></tr>
<tr><th colspan="3">Indian Code</th><th colspan="3">American Code</th></tr>
<tr><th>Concrete Grade</th><th>f’c (psi)</th><th>Ec (ksi)</th><th>Equivalent Concrete type</th><th>f’c</th><th>Ec = 57000√f’c (ksi)</th></tr>
<tr><td>M60</td><td>7000</td><td>5614.3</td><td>High strength concrete 28 days</td><td>7000 psi</td><td>4768.9</td></tr>
<tr><td>M40</td><td>4700</td><td>4584.3</td><td>Ordinary ready mix</td><td>5000 psi</td><td>4030.5</td></tr>
<tr><td>M15</td><td>1750</td><td>2807.2</td><td>Ordinary ready mix</td><td>3000 psi</td><td>3122.01</td></tr>
<tr><td colspan="3">fck is 28 compressive strength for 150mmx150mm cube.

Poission’s ratio = 0.2

Coefficient of thermal expansion = 9.9x10-0.6 per deg C.</td><td colspan="3">f’c - specified compressive strength of concrete.

Coefficient of thermal expansion = $5.5x10^{-6}$ per deg F.

Poissions ratio = 0.2</td></tr>
<tr><th colspan="6">Reinforcement</th></tr>
<tr><td colspan="3">According to IS: 1786 Fe 415 (Fy = 415 MPa/ 60 ksi) or Fe 500 (Fy = 500 MPa) steel bars are used.</td><td colspan="3">According to ASTM A615, deformed and plain carbon steel bars are used with Fy = 60 ksi.</td></tr>
</table>

Gravity Loads

The dead, superimposed and live loads used on the project are used from the IS Code whereas the report uses ASCE 7-10 provisions to calculate live loads. The superimposed dead loads are used the same that is on the project because they are loads from actual materials like floor finishes used on the project. The difference in live loads and calculation procedures like Live load reduction will cause difference in analysis results. However, the assumption is that indian code will give more conservative results because it accounts for contingencies in construction and materials used on the project. The tables below shows the difference in loading values between the IS code and ASCE 7-10 provisions.

- Typical Dead Loads

	IS Code (kN/ m^3)	ACI 318-11 / ASCE 7-10 (lb / ft^3)
Normal weight Concrete	25.00	150
Floor finishes / Plasters	20.00	140

Loading Area	Type of Load	IS Code (kN/ m^2)	ACI 318-11 / ASCE 7-10 (lb / ft^2)
Parking Space and Drive-way	Superimposed Dead Load	1.75	36.6
	Live Load (vehicles)	2.50 non-reducible	40 non-reducible
	Live Load (fire truck over ground floor)	15.00 non-reducible	300 (AASHTO LRFD Bridge design standards) - non-reducible
Covered Entryway over ground floor	Superimposed Dead Load	7.25	151.4
	Live Load	4.00	100
Entrance Lobby, Elevator lobbies	Superimposed Dead Load	2.00	41.8
	Live Load	3.00	100
Mechanical Floor	Superimposed Dead Load	2.00	41.8
	Live Load	7.50 Non-reducible	150 non-reducible
Electrical room over ground floor	Superimposed Dead Load	2.00	41.8
	Live Load	13.50 non-reducible	282 non-reducible

Loading Area	Type of Load	IS Code (kN/ m^2)	ACI 318-11 / ASCE 7-10 (lb / ft^2)
Stairs	Superimposed Dead Load	1.50	31.33
	Live Load	3.00	100
Toilet rooms	Superimposed Dead Load	4.50	94
	Live Load	2.00	40
Typical Office	Superimposed Dead Load	3.00	62.7
	Live Load	4.00	100
Retail over ground floor	Superimposed Dead Load	4.575	95.6
	Live Load	4.00	100
Eatery and Utility	Superimposed Dead Load	3.00	62.7
	Live Load	5.00	100
Outdoor Utility over Level 105, 107 and similar	Superimposed Dead Load	5.625	117.5
	Live Load	5.00	100
Planted Terrace	Superimposed Dead Load	12.50	261.1
	Live Load	3.00	100
Amenity / Fitness Center	Superimposed Dead Load	3.50	73.10
	Live Load	5.00	100
Water tank over level 119	Superimposed Dead Load	3.50	73.1
	Live Load	35 non-reducible	731 non-reducible
Electrical Panel room at ground floor	Superimposed Dead Load	2.00	41.8
	Live Load	13.50 non-reducible	282 non-reducible
Roof	Superimposed Dead Load	5.50	114.9
	Live Load	3.00 Non-reducible	100 non-reducible

Loading Area	Type of Load	IS Code (kN/ m^2)	ACI 318-11 / ASCE 7-10 (lb / ft^2)
Peripheral loads	Superimposed Dead line load over wall surface	0.75	15.7

- Live load reduction

According to IS 875 (part 2) - 1987, section 3.2, live load had been reduced.

<table>
<tr><th colspan="2">IS Code</th><th>ASCE 7-10</th></tr>
<tr><td colspan="2">Walls, columns, piers, their supports and foundation:</td><td rowspan="17">Reduction in live loads is carried out as per the provision in ASCE 7-10 Section 4.7.2/</td></tr>
<tr><td>Number of floors supported</td><td>% reduction in total live load</td></tr>
<tr><td>1</td><td>0</td></tr>
<tr><td>2</td><td>10</td></tr>
<tr><td>3</td><td>20</td></tr>
<tr><td>4</td><td>30</td></tr>
<tr><td>5 to 10</td><td>40</td></tr>
<tr><td>over 10</td><td>50</td></tr>
<tr><td colspan="2">Beams, girders and trusses</td></tr>
<tr><td>Supported Area</td><td>% reduction in total live load</td></tr>
<tr><td>less than $50m^2$</td><td>0</td></tr>
<tr><td>$50m^2$ to $100\ m^2$</td><td>5</td></tr>
<tr><td>$100m^2$ to $150\ m^2$</td><td>10</td></tr>
<tr><td>$150m^2$ to $200\ m^2$</td><td>15</td></tr>
<tr><td>$200m^2$ to $250m^2$</td><td>20</td></tr>
<tr><td>Over $250\ m^2$</td><td>25</td></tr>
</table>

Pro-Con Study of Floor Systems

The main purpose of the report is to analyze the existing floor system and comparing it with 3 alternative systems. The report analyses the existing flat slabs system with a composite floor system, metal deck on joist and joist girders and precast double tee slabs.

A typical bay of an office floor is taken into consideration for analyses. The bay size is 27.6’ x 27.6’ and loads considered are 100 psf live load, 62.7 psd superimposed dead load and dead load of the system in consideration. The live load is a conservative value because the floor is an open floor plan and the renters have the flexibility to design the partitioning, corridors, pantry rooms according to their choice. The 62.7 psf superimposed dead load comes from the floor finishes that might be used by the future tenant of the office space. Its only in the steel metal decking system where the superimposed dead load is reduced to minimize deflections due to service loads.

Using the typical bay and loads, all the floor system were compared based on its weight, cost, constructability and impact on structural and architectural systems. As the building is located in India, the cost and constructability are compared based on the conditions in India. The cost of labor is cheap which makes a concrete system cheaper; however, steel construction is expensive as steel buildings are rarely preferred and skilled labor for steel construction is expensive.

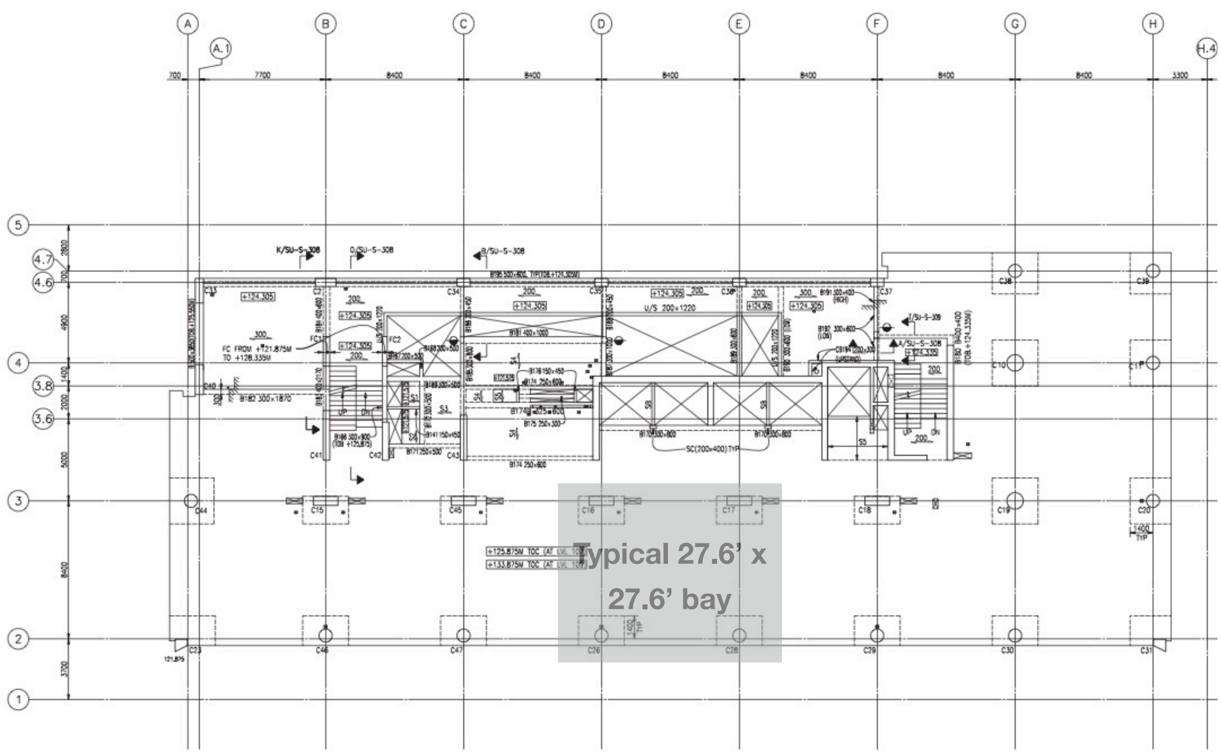


Fig. 6: Typical Office Floor Plan. Highlighted portion shows typical bay to be analyzed

Flat Slab with Drop Panels

All the typical office floors of The Optimus are designed as two-way flat slabs with drop panels. The slab is 8" thick typical size of drop panel is 4'6"x4'6" x 8". The primary purpose of the drop panel is to reduce deflections and punching shear in 27'6" long spanning slab. A secondary purpose is to help the slab increase the moment carrying capacity. However, this is majorly carried by the top and bottom reinforcement. The drop panels are not reinforced which proves that its does not provide much help to moment carrying capacity of the slab.

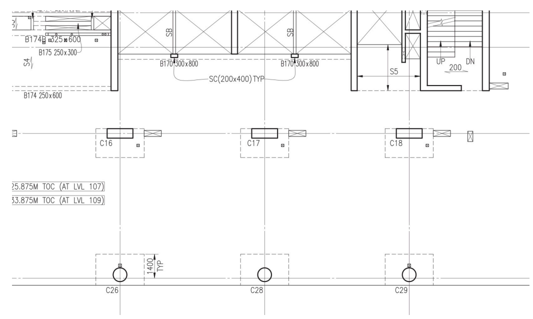


Fig. 7: Flat slab bay

All the floors are constructed using the M40 concrete which is equivalent to 5000psi concrete available in USA. In most of the floor area 8" slab is used. Slab depths have been increased to 11.5" in fire areas also called refuge areas where there is a higher chance of live load occurring during an event like fire. Because mechanical loads are approximated and not acquired from the mechanical consultant, the utility areas which house mechanical equipment have thicker slabs for a more conservative design.

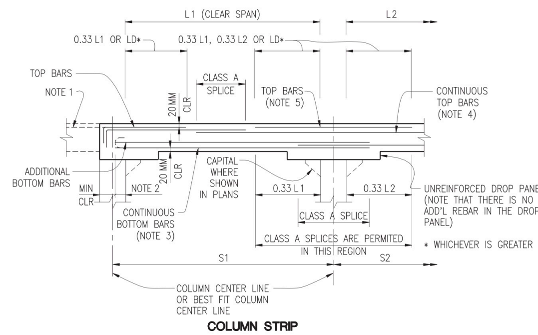


Fig. 8: Column Strip

The reinforcing in the flat slab consists of #3 bottom bars spaced at 11in and a combination of #3 and #14 top bars spaced at 6" to 11" distances. The columns are spaced at 27.6' in both direction to produce typical square bays for office spaces. The slab is design to carry partition loads and live loads from office spaces as well as facade loads at the perimeter of slabs.

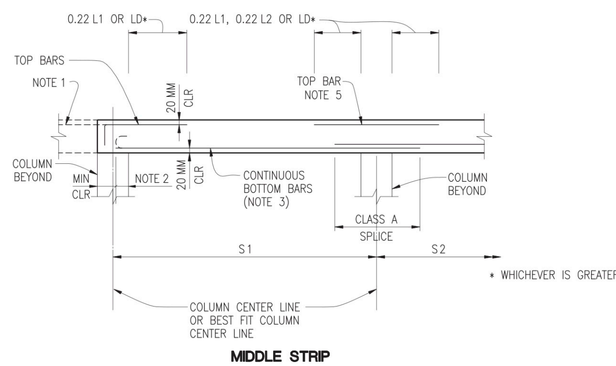


Fig. 9: Middle Strip

- General

The slab weights 98.5 pounds per square foot (psf) which is serving as a reference to compare the weights of the other alternative systems. The RS Means CostWorks website, gives latest cost information about each material and process carried out in the construction of the system. The flat plate system costs $14.8 per square feet according to RS Means and its National USA cost data. However, in the context of the construction practices in India this price would decrease because of cheap labor and less skill being in concrete construction. This would be the cheapest system among the other three systems. Also, concrete is a more widespread used product over Steel in India which makes it cheaper.

- Architectural

In India, architecturally it is preferred to use a false ceiling and hide the mechanical system above the false ceiling. Hence, Flat slab is one of the widely used floor systems as it provides a floor to ceiling height from 9' to 15' which is a preferred height in office spaces. A flat slab system improves the visual quality of the building form the exterior because it does not contain any beams or undulations in the ceiling surfaces except for the drop panels.This is another reason why a flat slab is considered widely in office and commercial buildings.

- Structural

According to the calculations carried out in the appendix, the slab passes in long term and total deflection checks as specified by ACI 318-11. Also, the slab passes in minimum thickness specified by ACI 318-11. The original design of the slabs was carried out using the Indian Standard Code. Besides transferring gravity loads to columns, the slab also transfers lateral forces: wind and seismic to the central core shear walls. An advantage to structural engineer with this system is that it becomes to easy to tackle design changes that occur before and after the constriction started.

- Construction

The flat slab system is easy to construct by formwork and pouring of concrete. It is easy to find cheap labor to work on the constructed building. This system takes time because this time is consumed by the curing period. The formwork is readily available for rent or purchase by the construction personnel as there is ample of construction going on in the location.

Pros	Cons
Low cost per square foot	High seismic weight
Cheap labor available at construction site in India	Longer construction time
Provides an even ceiling except for the drop panel	Deflection becomes and issue as spans become longer
Provides good floor to ceiling height	Drop panels are not preferred architecturally
Vibration is not an issue	

Composite Floor Slab system

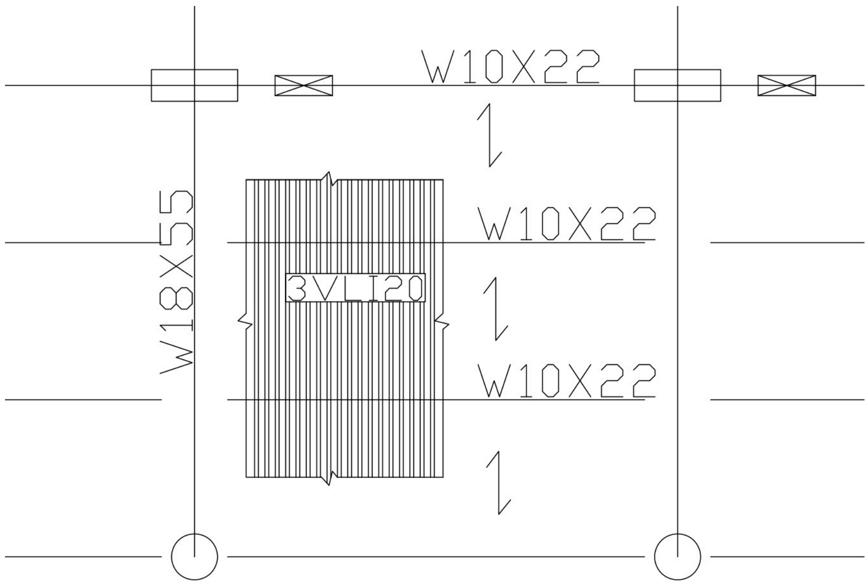


Fig. 10: Plan of Composite Flooring System

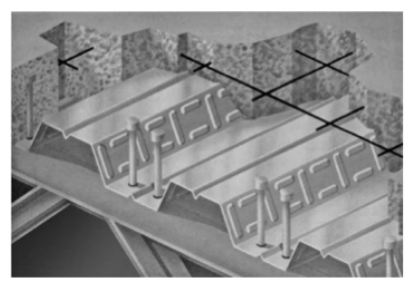


Fig. 11: 3VLI20 Metal Deck with concrete topping

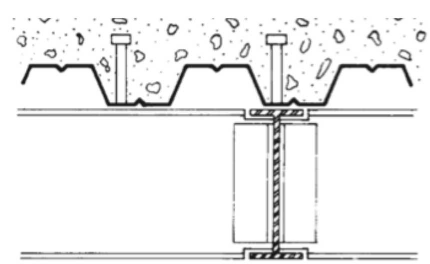


Fig. 12: Cross Section of composite section W10x22

In order to achieve spans as long as 27.6' with minimum depth of the slab system, a composite system was selected as the first alternative to be tried in place of a flat slab. W10x22 beam was chosen to support 3" deep 3VLI concrete deck topped with 4" concrete to take the compression load from the steel. The decking runs perpendicular to the 10x22 beam. This beam is supported on W18x55 composite girder which is designed with the deck running parallel on it.

The beam is spaced at 9.2' and spans 27.6' long. The girder spans 27.6' from one column to other. The beam sizes was controlled by live load deflections and design moments. Construction dead load was not used for design because it was assumed that shoring will be used while construction until the concrete reached at its maximum compressive strength. Shoring was considered as a cheaper option because shores and labor is cheaper instead of going for a larger beam depth that would compromise the floor to ceiling heights.

- General

The 7.5 in total thickness (metal deck and topping) with wide flange beams weighs 81.4 psf which is lower as compared to the flat slab system. This system costs about $10 per square foot which is the cheapest of all the floor systems. The reason for this system to be cheaper is that minimum formwork and labor is used on construction. If we put this in the context of construction in India, the price will go higher because of the use of steel and steel manufacturing laborers for erection.

- Architecture

As the depth of the composite system increases by 10”, the floor to ceiling height also reduces. This height reduces in the area where the girder is located, in the area below beams the depth of system is 17.5” which is only 1 in greater as compared to flat slab system. The space within the floor system can be used to mechanical ductwork through co-ordination between structural engineer, mechanical engineer and architect. The architect can choose to expose the structure in the ceiling which is found in several office spaces in USA but not a lot in India.

- Structure

The live loads induce a deflection of 0.698 in which is close to the deflections in a flat slab and higher than deflection in a precast member. Due to reduction in overall weight of the floor system the foundation sizes can be reduced. However, the foundation also supports the lateral pressures from the soils and water table pressures from the ground. An in depth analysis will be required to balance the effect of load reduction on foundation and the soils pressures. Use of composite system will lead to change in the lateral system from concrete to steel frame. A steel braced or moment frame or a combination could be used as lateral force resisting system.

- Construction

As mentioned earlier, its assumed that labor force will be available for composite floor system. As shoring is considered, part of the job of labor force will be to install and dismantle the shoring. As the concrete topping is 4.5 in, the floor system has a fire rating of 2 hr.

Pros	Cons
Lowers weight of the building	Higher cost due to steel being expensive in India
Longer spans can be achieved	Also, steel construction laborers are expensive in India
Structure can be exposed for a different architectural feel which can be unique for a building in India	Serviceability could be an issue
Less formwork required	

Steel metal deck and Joist System

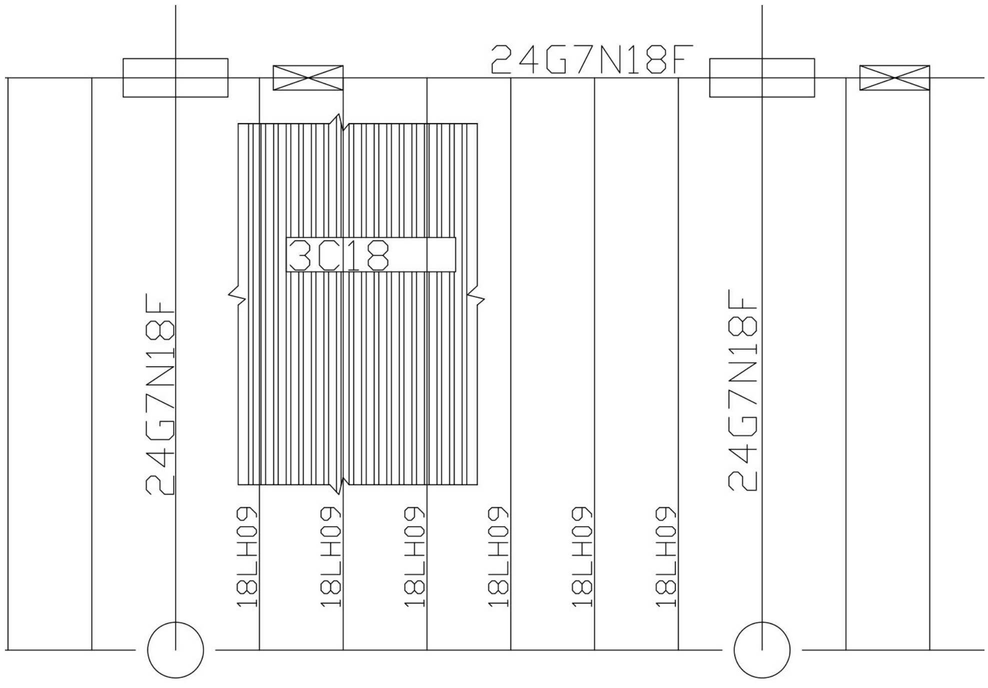


Fig. 13: Floor Plan of Steel decking, joists and joist girder

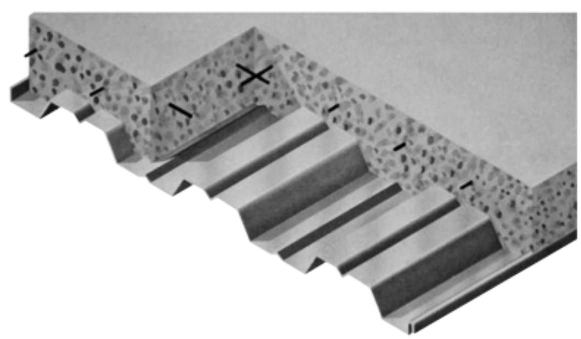


Fig. 14: 18C09 steel deck with 3" Concrete topping

After looking into concrete and composite systems, the implications of a complete steel system was worth looking into. Using hand calculations, vulcraft deck catalog and steel joist institute catalog, a steel system design was carried out which consisted of steel metal decking topped with 2" concrete reinforced with welded wire fabric. The decking rested on long haul steel joists and a steel joist girder.

Live load deflections and superimposed dead loads were used to select the decking and joists. A 3 in deep 3C18 steel deck topped with 3in concrete was selected. A steel joist 18" deep 18LH09 was selected to support the decking and the joist was resting on 24" deep joist girder 24G7N18F. 7 18" joists supported the decking slab, 2 joists rested directly on the columns and 5 joists supported on 24" joist girder.

- General

The steel metal deck and joist system is the lightest among all the floor systems and ranks 2nd from a cost perspective. This system costs $15.1 per square feet. Due to steel as a material and its accurate construction methods, the cost of construction would be higher in India. The depth of the system in the area were joist girder exits is 36” and the depth in the area of joist beams is 24”.

- Architecture

The change from a complete concrete to a steel system undergoes a lot of architectural changes. In order to adjust the floor-ceiling height, the overall height of the building need to be increased. Although this system has large depths, the ceiling can be used to run mechanical ductwork through the joists. This requires accurate co-ordination in the design team between and structural and mechanical engineer. Also, the columns spacing might need to be reduced to decrease the depth of the system.

- Structure

A steel framed floor system requires steel columns and it goes through a significant load reduction as compared to concrete. Also, size reduction occurs in foundations after a balance is achieved between the soil bearing capacity, lateral earth pressures and the overall weight of the building. The lateral system will change to steel braced or moment frame or a combination. Converting to steel is one of the ways of making building greener as steel is a recyclable material and results in lighter building.

- Construction

Steel construction is the fastest of the all three systems. However, it requires skilled labor onsite and construction precision which comes with a price.

Pros	Cons
Very light as compared to comcrete systems	Expensive due to steel and labor being expensive in India
Reduces foundation sizes	Serviceability could be an issue
Smaller column cross-sections will provide a better open floor plan	Columns spacing need to be reduced for higher floor to ceiling height
Steel can be recycled; promotes a sustainable building	Design change at the time of construction could be an issue due to pre-fabrication of steel
	Large system depth due to long spans

Precast Double Tee Floor System

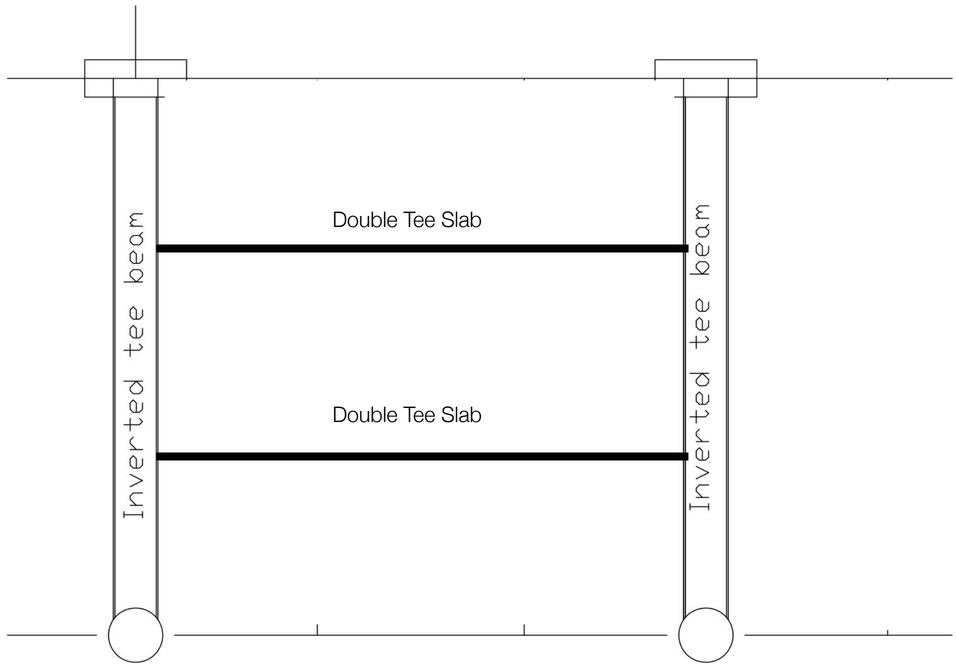


Fig. 15: Plan of Precast slabs and inverted tee

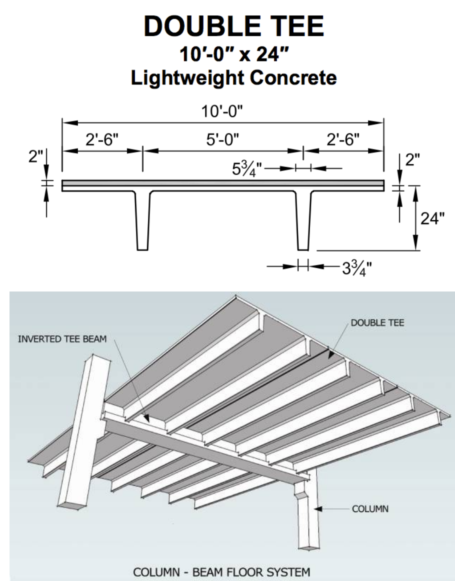


Fig. 16: Precast Slab rendering detail

The fastest way to achieve a building that is concrete is using a precast system. The concrete members are prefabricated in a factory in controlled conditions. The conditions in a manufacturing plant result in a members with higher quality. Prestressed double tee members are used which are 10 feet wide and 24 in deep. The double members are supported on prestressed inverted tee girders that carry the load to the columns.

The floor system is designed using the handbook of the Precast Concrete Institute (PCI) where members are selected using the service loads. As members are prestressed, long spans can be achieved.

General

The weight of a precast double tee is 74 psf which is the second lightest after steel metal deck system. It is the most expensive system at $17.6 per SF because, it also requires skilled laborers to lay the members on site and connect them to girders and columns. Also, transporting the large member is a concern. The depth of the girder is 36” and the depth of system at the double tee is 24”. The beams can be aligned in a way to allow space for mechanical ductwork and electrical wiring.

Architecture

This system might not be a preference of the architects because of the maximum depth of the system - 36”. The only way to overcome this large depth is by increasing the overall height of the building. An architectural advantage of this system is using the long span capability and increasing the bay sizes, thus reducing the columns. This will help in achieving a more open floor plan which is desired in The Optimus.

Structure

The structural system acts like composite and flat slab system. The reduced weight will help reduction in foundations. In situation where there is no space for foundations and long spans occur, the prestressed precast system works perfectly. The lateral system will remain as concrete shear wall. Also, just like steel moment frame, a moment frame can be designing moment connections of precast members. The double tee and inverted tee members used are simplified as pin connections. They were checked for maximum live load deflection of 0.47 in.

Construction

The construction of precast system is similar to erecting a steel system. Precast members are transported from factory to construction site. They are placed using cranes. This precess eliminates the process of concrete curing. Hence, making it faster. One of the drawbacks is that that design changes after or during construction is difficult as members get casted in the plant. Hence, co-ordination among design teams is very important in constriction of a precast system.

Pros	Cons
Efficient members can be manufactured by offsite curing of concrete	Transportation of members to site could be issue in tight spaces
Increases construction schedule	High cost
	Difficult to modify after design is cone
	Reduces floor to ceiling height

Comparison table of Floor Systems

Criteria		Two way flat plate with drop panels (Existing system)	Composite Steel	Metal deck with steel joists	Precast Double Tee with precast inverted tee girder
General	Weight (psf)	98.5	81.4	58.5	74
	Cost ($/SF)	14.8	9.5	15.1	17.6
	Maximum depth of system	16” at drop panels	25.5” to the base of the girder	30” to the base of the joist girder	36” to base of girder
Architectural	Bay size change	N.A	Not required	Lower bay size to increase floor height	Not required
	Fire Rating	2 hr	2 hr	2 hr	2 hr
Structural	Impact on foundation	Existing Mat foundation	Size / Capacity can be reduced	Size / Capacity can be reduced	Size / Capacity can be reduced
	Impact on gravity system	Existing concrete columns	Steel or composite columns can be used	Steel columns can be used	Concrete columns required
	Impact on lateral system	Concrete Shear wall core	Steel or concrete option	Steel braced frame required	Concrete shear wall core
	Maximum immediate deflection	0.670 in	0.698 in	NA	0.47 in
	Ease of post design modification	Easy as concrete is poured on site	Easy because concrete is used by steel members are prefabricated	Difficult because members are prefabricated	Difficult because members are prefabricated
Construction	Impact on labor force	Does not require skilled labor	Requires labor skilled in steel construction	Requires labor skilled in steel construction	Required labor skilled to erect prefabricated concrete members
	Impact on schedule	N.A	May reduce construction schedule	May reduce construction schedule	May reduce construction schedule
	Constructability	Easy	Medium	Difficult	Medium
Feasibility		N/A	Yes	No	Yes

Conclusion

Technical report 2 analyzed the existing floor system of The Optimus and compared it three alternative floor system design choices. A typical bay of office floor was selected to design and size the 3 floor systems. Common live loads and superimposed dead loads were used to size members based on moment capacity and deflections. The comparison in the systems was based on weight of the floor system, cost, constructability and impact on architecture and structure of the building. The intent was to achieve a system that balances out the three main characteristics to achieve an efficient system: weight, cost, floor to ceiling height.

The existing flat slab system is the heaviest of the four systems and the second least expensive. As there are a lot of contingencies involved in the loading, construction and design of the building in India, flat slab is one of the preferred system.

The composite system is the next most efficient system after flat slab because it is lighter and it ranks medium in terms of constructability as flat slab. The use of steel is the only factor that makes the system cost higher as compared to flat slab.

The third choice is a precast system that maximizes construction time, reduces labor and reduces weight. One significant limitation is that it has a large depth which lower floor to ceiling height.

A steel decking on joists is least considered system because it is expensive, it had large depth and constructability in the construction conditions in India would make it expensive.

A further in-depth analysis would help prove a more efficient system between flat slab and composite system.

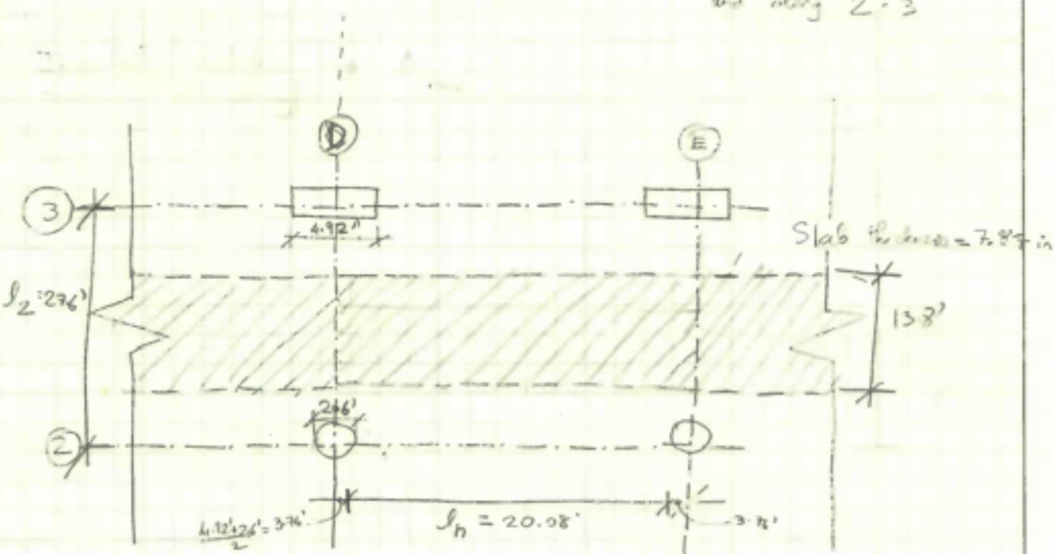
Appendix 1: Flat Slab

Flat Slab check | Tech 2 | Punit G Das | 1

Checking Immediate & long-term deflection at most critical area in the typical selected slab area

- Calculating deflections for typical slab panel D-E-2-3
  - Immediate deflections
  - Long term deflections

  } along the middle strip between grid D-E and along 2-3



@ Ma and M_{cr}

(1.0) Dead load = $\left(\frac{7.87 \text{ in}}{12 \text{ in}}\right) 150 \frac{lb}{ft^3}$ + 62.7 = 161.1 psf

(1.0) Service load (dead + live) = 161.1 + 100 → = 261.1 psf

(2.0) Construction load (slab dead load) = 2 × 161.1 → = 322.2 psf

Factored load on slab: 1.2D + 1.6L = 1.2(201.1) + 1.6(100) = 401.3 psf

$\frac{\text{Construction load}}{\text{Factored load}} = \frac{322.2}{401.3} = 0.803$

2

(b) Calculating moments using Direct Design Method

ACI 318-11

All limitations of Direct design Method from 13.6.1.1 – 13.6.1.5 are satisfied.

- ✓ Minimum of 3 column spans in each direction
- ✓ Ratio of long to short spans < 2 (two way system)
- ✓ Successive spans lengths in each direction $\frac{1}{3}$rd the longer span
- ✓ Adjacent span > $\frac{2}{3}$ of longer span.
- ✓ Column offsets dont exist
- ✓ All loads are gravity loads

ACI 318-11
13.6.2,
equation 13-4

$$M_o = \frac{q_u l_2 l_n^2}{8}$$

$q_u = 1.2D + 1.6D = 401.3$ psf

$l_2 = 27.6'$

$l_n = 20.08'$

$M_o = \underline{558.2}$ k-ft

ACI 318-11
13. 6.3.2

For interior span,

Negative factored moment $= 0.65M_o = \underline{362.8 \text{ k-ft}}$

Positive factored moment $= 0.35M_o = \underline{195.37 \text{ k-ft}}$

$$\frac{l_2}{l_1} = \underline{1.375} \text{ k-ft}$$

Using ACI 318-11
13.6.4.1 &
13.6.6

Factored moment in middle strips

Positive $= (1 - \underline{0.6375})\,0.35M_o = \underline{70.8}$ k-ft

Negative $= (1 - \underline{0.6375})\,0.65M_o = \underline{131.5}$ k-ft

For construction loads

$M_a^+ = (0.803) \times (0.6375)(.35M_o) = \underline{100.91}$ k-ft

$M_a^- = (0.803) \times (0.6375)(0.65M_o) = \underline{185.7}$ k-ft

3

(C) Compute M_{cr}, I_e, I_{cr}

ACI 318-11 eq. 9-9 ← $M_{cr} = \frac{f_r I_g}{y_t}$

ACI 318-11 eq. 9-10 ← $f_r = 7.5\sqrt{f'_c}$

According to Text book Reinforced Concrete by McGregor and Wight

f'_c for 14 day old slab strength $= 0.88 f'_c$

so $f_r = 7.5\sqrt{0.88 f'_c}$
$= 7.5\sqrt{0.88(4700)}$
$= \underline{482.3}$ psi

$$I_g = \frac{(13.8' \times 12)(7.87\text{ in})^3}{12} = \underline{6726.7}\text{ in}^4$$

$$y_t = \frac{7.87}{2} = \underline{3.94}\text{ in}$$

$$M_{cr} = \frac{(482.3)(6726.7)}{(3.94)(1000)(12)} = \underline{68.6}\text{ k}\cdot\text{ft}$$

$$I_{cr} = \frac{1}{3} b d^3 + A_s\left(\frac{E_s}{E_c}\right)(d - kd)^2$$

for negative moment region $d = \underline{7.1"}$ from drawing $\underline{S4\text{-}20}$

$\rho = \frac{A_s}{bd} = \frac{(13)(0.12)}{(13.8)(7.1)}$

$n = \frac{29000000}{57000\sqrt{0.88(4700)}}$

$\rho = 0.0159$
$n = 7.91$

$n\rho = \underline{0.291}$ ⟹ $k = \underline{0.376}$ from eq^n

$k = \sqrt{2\rho n + (\rho n)^2} - \rho n$

$$I_{cr} = \frac{1}{3}(13.8 \times 12)\left[0.376 \times 7.1\right]^3 + (13 \times 0.12) \times \left(\frac{29000}{4584.3}\right)(7.1 - 0.376 \times 7.1)^2$$

$I_{cr} = \underline{1243.9}$ in^4

4

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

ACI-318-11 eq 9-8 ⟶ $I_e = \left(\frac{M_{cr}}{M_a}\right)^3 I_g + \left[1-\left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr}$

for positive moment: $I_e^+ = \left[\left(\frac{68.6}{100.01}\right)^3 (6726.7)\right] + \left[1-\left(\frac{68.6}{100.1}\right)^3\right](1243.9)$

$= \underline{3013.4}\ in^4$

for negative moment: $I_e^- = \left[\left(\frac{68.6}{185.7}\right)^3 (6726.7)\right] + \left[1-\left(\frac{68.6}{185.7}\right)^3\right](1243.9) = \underline{1520.3}\ in^4$

(d) Immediate & long term deflections

$w_D = \frac{(161.1\ psf) \times 27.6'}{1000} = \longrightarrow \underline{4.45}\ k/ft$

$w_L = \frac{100\ psf \times 27.6'}{1000} = \underline{2.76}\ k/ft$

Deflection coefficient from Wight & Megregor Table 9-2, pg 449

$\Delta_{D_{max}} = 26\times10^{-3}\frac{w_D \times l^4}{E_c I_e^+} \times 12^3 = \frac{(26\times10^{-3})(4.45)\times(20.8)^4\times12^3}{(3907.7)(3013.4)}$

$= \underline{0.27603}\ in$

$\Delta_{L_{max}} = \frac{0.0048\ w_L \times l^4}{E_c I_e^+} \times 12^3 = \underline{0.3161}\ in$

Assuming 25% of live load is sustained for long time, then

ACI 318-11 eq 9-11 ⟶ $\lambda_\Delta = \frac{\xi}{1+50\rho'} = \frac{2}{1+50\left(\frac{A_s'}{bd}\right)} = \underline{2.0}$ at midspan.

→ no top bars

$\Delta_{(long-term)} = \lambda_\Delta\left(\Delta_{D_{max}} + 25\%\Delta_{L_{max}}\right) = \underline{0.710}\ in$

According to ACI 318-11 Table 9-5(b) ⟶ $\Delta_{L_{immediate}} = \frac{l}{360} = 0.67 > 0.276\ in$ OK

$\frac{l}{240} = 1.004\ in > 0.710\ in$ OK

Flat Slab Check	Tech 2	Punit G Das	5

ACI 318-11
Table 9.5(c)

Minimum thickness of slabs with drop panel & without edge beams.

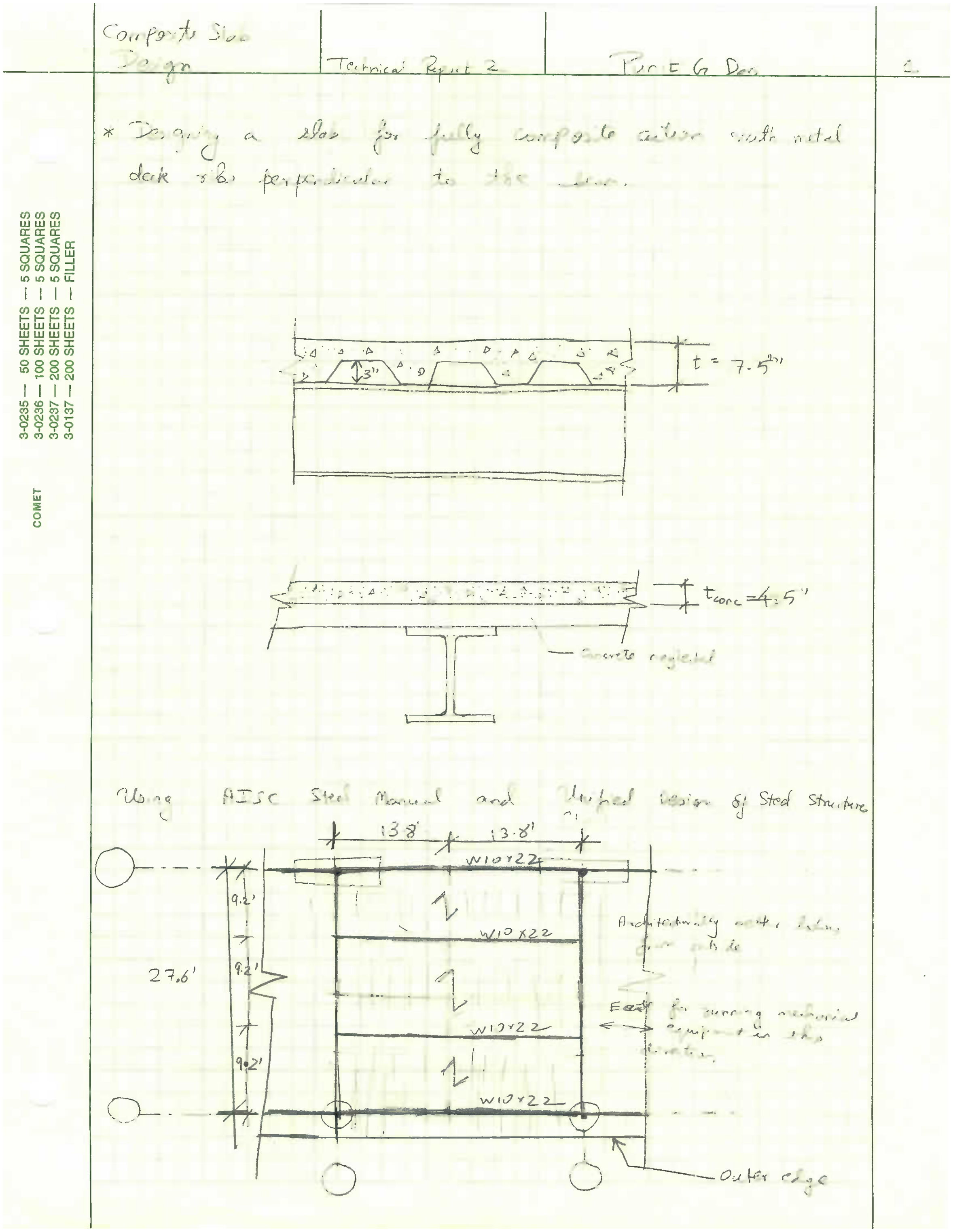
$f_y = 60{,}000$ psi

for interior panel → $\frac{l_n}{36} = \frac{(20)(12)}{36} = 6.67 < h = 7.87$ in
OK

for exterior panel → $\frac{l_n}{32} = 7.5$ in $< h = 7.87$ in
OK

Critical l_n = 20.08 ft

Appendix 2: Composite



2

(1.) • Selection of steel deck. using AISC specification section I 3.2c.

• Using Vulcraft Deck catalog to select a composite deck.

— Loads

(CDL) Construction dead load = 161.1×2 = 322.2 psf (taken from Flat Slab check)

Typical office SDL → 62.7 psf

Typical office LL → 100 psf

DL → 75 psf.

$$M_u = \frac{wl^2}{8} = \frac{(1.2D + 1.6L)\, l^2}{8} = \frac{(325.24\,psf)(9.2')(27.6')^2}{8}$$

$M_u = 284.9\,k\text{-}ft$ is and for CDL $M_u = 282.3\,k\text{-}ft$ –

— Selecting a 3VLI deck using Vulcraft deck Catalog

Deck type: 3VL20

Superimposed Live load → 100 psf

So 3 span 9.2' long, too

more concrete will be cheaper than more steel

Vulcraft Deck Catalog Pg 53

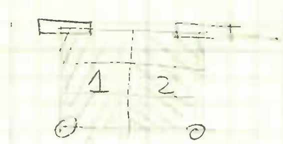
3VLI20, 3 spans, span length – 11'

Clear span of 13'6,

Concrete Topping thickness – 4.5"

DL → 75 psf

Therefore, 2 sheets of deck per bay required.



3

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

Checking AISC requirements, (AISC Section I3)

rib height = 3" OK

average rib width = 7.25 > 2 in OK

concrete slab thickness = 4.5" > 2 in OK

(2.) Selecting and analyzing a wide flange beam for fully composite action.

$b' \leq \frac{span}{8} = \frac{27.6}{8} = 3.45'$

$b' \leq \frac{1}{2}(9.2) = 4.6'$

So, $b_{eff} = 2b' = \underline{6.9'} = \underline{82.8"}$

Trying a W16x26 beam.

(1.) $V'_c = 0.85 f'_c \, t \, b_{eff} = (0.85)(4)(4.5)(82.8)$

$V'_c = 1266.8k$

$V'_s = A_s f_y = (7.68)(50) =$

$V'_s = 384k$

So, $V'_s < V'_c$, steel controls and PNA is at the top of flange or above.

(2) To find the depth of concrete acting in compression

$a = \frac{\Sigma Q_n}{0.85 f'_c b_{eff}} = \frac{384k}{(0.85)(4)(82.8)} = \underline{1.36 \text{ in}}$

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

4

(3) Moment arm of the compressive force from top of steel

$$Y2 = 7.5 - \frac{1.36}{2} = 6.82\,in$$

So, from AISC Table 3.19

$$\phi M_n = 422.6 \text{ ft-k} > 284.9 \text{ k-ft}$$

But ϕM_n for W16x26 beam = 49.1 k.ft for 27' span.

$\phi M_{n\,W16x26} < \phi M_u$ due to CDL

So, the beam requires shoring.

Trying W12x16

$V'_c = 1266.8k$ $V'_s = 4.71(50) = 235.5k$

$$a = \frac{236}{(0.85)(4)(82.8)} = 0.838''$$

$$Y2 = 7.5 - \frac{0.838}{2} = 7.01'' \approx 7'$$

$\phi M_n = 230$ k.ft $< M_u = 284$ ft.k

Trying W10x22

$V'_c = 1266.8k$ $V'_s = (6.49)(50) = 324.5k$

$$a = \frac{325}{(0.85)(4)(82.8)} = 1.15''$$

$$Y2 = 7.5 - \frac{1.15}{2} = 6.9 \approx 7''$$

$\phi M_n = 294$ ft-k $> \phi M_u = 284$ ft-k

So W10x22 works

(3) Design of shear studs using AISC Spec. I8
Table 3-21

A $\quad \Sigma Q_n = 325k = 0.5 A_{sa} \sqrt{f'_c E_c} \leq R_g R_p A_{sa} F_u$.

diameter of shear stud $\leq (2.5) t_f$

Using Table 3-21

- Deck runs perpendicular to beam
- Assuming weak studs per rib ($R_p = 0.6$) (conservative)
- 3 span deck
- Normal weight concrete $f'_c = 4ksi$
- 3/4" diameter studs are common

so, $Q_n = 15.1k$ per stud. (Table 3-21)

Total number of studs $= \frac{325}{15.1} \approx$ **22 studs per rib**

(4) Deflection Check Using (Table 3-20) AISC (& Commentary in Section I3.2)

$I_{LB} = 593 \text{ in}^4$, for $Y2 = 7$, W10x22, $\Sigma Q_n = 325k$

$$\Delta_{LL} = \frac{5wl^4}{384EI} = \frac{(5)\left[\frac{100 \times 9.2}{1000}\right](27.6)^4 (1728)}{(384)(29{,}000)\,593}$$

$$\Delta_{LL} = 0.698 \text{ in.} < \frac{span}{360} = \frac{(27.6)(12)}{360} = 0.92 \text{ in}$$

Ok ✓

So, W10x22 with 3VLI 20 metal deck with 4.5" concrete slab system is chosen. 3/4", 20 studs per rib is required.

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER

COMET

Designing girder.

Selecting economical wide flange for 3VLI 20 metal deck with 4.5" concrete slab on it.

* Loads

$DL = \left(75 \text{ psf metal deck w/ concrete}\right) \times 27.6' + (22 \text{ plf}) \times 2$

$= 2.114$ klf

SDL = 62.7 psf × 27.6' ⟶ 1.73 klf

LL = 100 psf × 27.6' ⟶ 2.76 klf

Factored load $= W = 1.2D + 1.6L = 902$ plf

Factored moment $= M_u = \frac{wl^2}{8}$ for $l = 27.6' = 860$ k·ft

$V'_c = 1266.8k$

* Try W 18x55.

↓

$a = \frac{\Sigma Q_n}{0.85 f'_c b_{eff}} = \frac{810}{(0.85)(4)(82.8)} = 2.9"$

⟶ is same because span is same as beam.

$Y2 = 7.5 - \frac{a}{2} = 6.1" \approx 6"$

$\phi M_n = 914$ k·ft > 860 k·ft OK

* Shear studs design

$\Sigma Q_n = 810k$

From Table 3-21,

$f'_c = 4ksi$. Deck runs parallel to beam

$\frac{W_r}{h_r} = \frac{7.25}{3} = 2.42 > 1.5$, $\frac{3}{4}$" diameter $Q_n = 21.5k$

Total studs required per rib = $\frac{810}{21.5}$ ≈ 38 studs

Deflection check.

$I_{LB} = 2720\ in^4$ from Table 3-20.

$$\Delta_{LL} = \frac{(5)(2.78)(27.6)^4(12^3)}{(384)(29000)(2720)} = 0.457 < \frac{l}{360} = \frac{(27.6)(12)}{360} = 0.92\ in$$

OK

So, W18x55 girder with 3VLI metal deck, 4.5" concrete slab on top and 38 studs per rib.

Appendix 3: Steel Metal Decking

Concrete on Metal Deck Floor System	Technical Report 2	Punit G. Das	1

Designing a Steel Metal deck floor system with wide flange joists and girders.

(1.) Selecting a metal deck from Vulcraft Deck catalog.

(Reducing SDL by 50% for steel construction)

Loads : Superimposed live : 30 psf ←

Live load : 100 psf

Typical Column Spacing : 27.6' Using this column spacing to design steel metal deck floor system.

Notes : (1) Slabs will have concrete topping

(a) 3 span continuous deck, sp 9.2' per span.
2.5" Normal weight concrete topping.

(b) Selecting a 2C Conform from Vulcraft Deck catalog

* Max construction clear span → 9'4 > 9.2, for 3 spans
→ 2C22 Deck with 44 psf deck load.

→ Total slab depth → 4.5"

* Total load = LL + SDL + Deck load
= 100 + 30 + 44
= 174 psf < Any type of 2C deck with 3 span condition.

Trying a 3C conform deck.

3-0235 — 50 SHEETS — 5 SQUARES
3-0236 — 100 SHEETS — 5 SQUARES
3-0237 — 200 SHEETS — 5 SQUARES
3-0137 — 200 SHEETS — FILLER
COMET

2

(c) Try a 10'1, 3span 3C22 deck. ~~with~~ 56 psf slab load, 3" concrete topping

10'1 > 9'2 (span)

~~3C22~~ Total load = 100 psf (LL) + 30 psf (SDL) + 56 psf
= 186 psf.

LL = 100 psf

for 9'6 clear span total load = 140 psf < 186 psf

does not work.

try a 3C18 deck, 3span with 3" concrete topping

slab, deck load = 57 psf.

so max span = 14'2 > 9'2 ok

Total load = 187 psf

✓ Allowable total load for 9'6 span = 241 psf > 187 psf
OK

✓ Allowable live load for 9'6 span = 181 psf > 100 psf
OK

So, 3C18 deck with 3" concrete topping works for 9'2 per span & 3span bay

3

② Designing a Steel joist to support the deck slab

Loads: DL = Slab deck load = 57 psf

SDL = ⟶ = 30 psf

LL = ⟶ = 100 psf

Span: 27.6'

Typical bay size = 27.6' × 27.6' with 3 spans of joists

Tributary width for a joist = 9.2'

* Using Steel Joist Catalog to design a LH-series joist

Total Factored load = $(1.2DL + 1.6L)\,9.2' = [(1.2)(57) + 1.6(100)]\,9.2$

$= \underline{2432\ plf}$ (too high)

Unfactored Live Load = 100 psf

With 6 spans of 4.6' tributary width we get

Total factored load = 1216.2 plf

and we can select 18LH09 joist which is 18" deep

Total live load = 100 psf × 4.6' = 460 plf

460 plf < $\underline{491\ plf}$ OK

↓ Live load for 18LH09 joist at 28'

So, <u>18LH09 joist from SJI catalog</u>

(3) Selecting a joist girder using SJI catalog

(a) Point loads

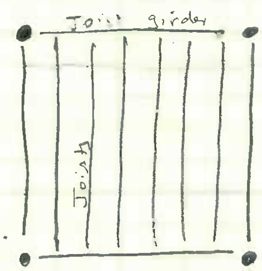
Unfactored Dead load per joist = [21 plf (Joist weight) + 262.2 plf (DL) + 138 plf (SDL)] $\frac{27.6'}{2}$

= 5812 lb

Unfactored Live load per joist = (460 plf) $\frac{27.6'}{2}$

= 6348 lb

Total factored load



6 spans in a bay → 7 joists → 2 joists on columns
so, 5 joists on a girder

Total factored load = [(1.2 × 5812) + (1.6 × 6348)] × 5

= 85.7 kip

Total live load = 6348 × 5 = 31.7 kip

(b) Selecting a Joist Girder

Girder span → 27.6' ≈ 28'

Joist spaces → 7 spaces @ 4.6' ≈ 7 spaces @ 4'

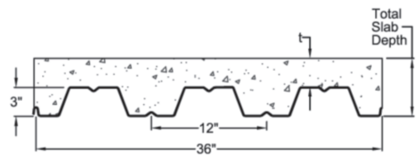
Girder depth → 24"

Joist girder weight → for 17.1 k load at each panel point → 6 plf

So, 24G 7N 18F joist girder from SJI Catalog

VULCRAFT

3 C CONFORM



Interlocking side lap is not drawn to show actual detail.

NON-COMPOSITE

MAXIMUM CONSTRUCTION CLEAR SPANS (S.D.I. CRITERIA)

Total Slab Depth	DECK	WEIGHT PSF	NW CONCRETE N=9 145 PCF			WEIGHT PSF	LW CONCRETE N=14 110 PCF		
			1 SPAN	2 SPAN	3 SPAN		1 SPAN	2 SPAN	3 SPAN
6 (t=3.00)	3C22	56	8- 4	8- 10	10- 1	43	9- 3	10- 9	11- 9
	3C20	57	9- 8	11- 10	12- 3	43	10- 9	13- 1	13- 6
	3C18	57	11- 10	14- 2	14- 2	44	12- 11	15- 2	15- 2
	3C16	58	12- 2	14- 4	14- 10	45	13- 7	15- 9	16- 0
6.5 (t=3.50)	3C22	62	8- 0	8- 3	9- 4	48	8- 11	10- 0	11- 4
	3C20	63	9- 3	11- 5	11- 9	48	10- 4	12- 7	13- 0
	3C18	63	11- 4	13- 9	13- 10	49	12- 7	14- 9	14- 9
	3C16	64	11- 7	13- 10	14- 3	49	13- 0	15- 2	15- 7
7 (t=4.00)	3C22	68	7- 9	7- 8	8- 8	52	8- 7	9- 4	10- 8
	3C20	69	9- 0	10- 11	11- 4	53	9- 11	12- 2	12- 7
	3C18	69	11- 0	13- 3	13- 6	53	12- 3	14- 5	14- 5
	3C16	70	11- 4	13- 4	13- 9	54	12- 6	14- 9	15- 3
7.5 (t=4.50)	3C22	74	7- 7	7- 2	8- 2	57	8- 3	8- 10	10- 0
	3C20	75	8- 9	10- 2	11- 0	57	9- 7	11- 10	12- 2
	3C18	75	10- 9	12- 10	13- 3	58	11- 9	14- 2	14- 2
	3C16	76	11- 0	12- 11	13- 4	59	12- 1	14- 3	14- 9
8 (t=5.00)	3C22	80	7- 5	6- 9	7- 8	61	8- 0	8- 4	9- 5
	3C20	81	8- 7	9- 7	10- 8	62	9- 3	11- 6	11- 10
	3C18	81	10- 6	12- 5	12- 10	62	11- 5	13- 10	13- 11
	3C16	82	10- 9	12- 6	12- 11	63	11- 8	13- 11	14- 4

REINFORCED CONCRETE SLAB ALLOWABLE LOADS

Slab Depth	REINFORCEMENT		Superimposed Uniform Load (psf) -- 3 Span Condition, Clear Span (ft.-in.)										
	W.W.F.	As	6- 6	7- 0	7- 6	8- 0	8- 6	9- 0	9- 6	10- 0	10- 6	11- 0	11- 6
	6X6-W2.9XW2.9	0.058*	**125**	**108**									
6	4X4-W2.9XW2.9	0.087	**185**	**160**									
(t=3.00)	4X4-W4.0XW4.0	0.120	**246**	**212**									
	6X6-W2.9XW2.9	0.058*	**154**	**133**	**116**	**102**							
6.5	4X4-W2.9XW2.9	0.087	**229**	**198**	**172**	**151**							
(t=3.50)	4X4-W4.0XW4.0	0.120	**306**	**264**	**230**	**202**							
	6X6-W2.9XW2.9	0.058*	**183**	**158**	**138**	**121**	**107**	**96**					
7	4X4-W2.9XW2.9	0.087	**273**	**235**	**205**	**180**	**159**	**142**					
(t=4.00)	4X4-W4.0XW4.0	0.120	**366**	**316**	**275**	**242**	**214**	**191**					
	4X4-W2.9XW2.9	0.087*	**316**	**273**	**238**	**209**	**185**	**165**	**148**	**134**	**121**		
7.5	4X4-W4.0XW4.0	0.120	**400**	**368**	**320**	**281**	**249**	**222**	**200**	**180**	**163**		
(t=4.50)	4X4-W5.0XW5.0	0.150	**400**	**400**	**392**	**345**	**306**	**273**	**245**	**221**	**200**		
	4X4-W2.9XW2.9	0.087*	**360**	**310**	**270**	**238**	**210**	**188**	**168**	**152**	**138**	**126**	**115**
8	4X4-W4.0XW4.0	0.120	**400**	**400**	**365**	**321**	**284**	**254**	**228**	**205**	**186**	**170**	**155**
(t=5.00)	4X4-W5.0XW5.0	0.150	**400**	**400**	**400**	**395**	**350**	**312**	**280**	**253**	**229**	**209**	**191**

NOTES:
1. * As does not meet A.C.I. criterion for temperature and shrinkage.
2. Recommended conform types are based upon S.D.I. criteria and normal weight concrete.
3. Superimposed loads are based upon three span conditions and A.C.I. moment coefficients.
4. Load values for single span and double spans are to be reduced.
5. Vulcraft's painted or galvanized form deck can be considered as permanent support in most building applications. See page 23. If uncoated form deck is used, deduct the weight of the slab from the allowable superimposed uniform loads.
6. Superimposed load values shown in bold type require that mesh be draped. See page 23.

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Appendix 4: Precast Floor System

Designing Precast floor system using specification from PCI Design handbook

(1.) Loads

Superimposed dead load = 62.7 psf
Live load = 100 psf
Safe Superimposed load = Service load = 162.7 psf

(2.) Selecting a system that spans longer.

Try a Double-tee → 10DT24,
10' wide, 24" double tee with 4" thick top flange. Using Normal weight concrete $f'_c = 5000$ psi

Strand pattern → 68S, 30 ft span.
171 psf > 162.7 psf OK

estimated camber – 0.6" at erection
Weight of the member = 74 psf

(3) Deflection check

$$W = 1.2D + 1.6L = 1.2\left[\underset{DL}{74\times10'} + \underset{SDL}{62.7\times10'}\right] + 1.6\left[100\times10'\right]$$

$$= 3.24\ k/ft$$

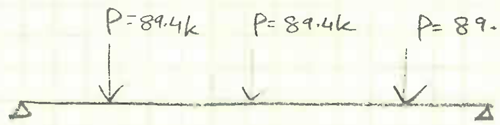
$$\Delta_{LL} = \frac{5wl^4}{384EI} = \frac{(5)(3.24)(27.6)^4(12)^3}{(384)(4030.5\ ksi)(22469)} = 0.467\ in$$

$$\Delta_{LL} = \frac{l}{360} = \frac{(27.6)(12)}{360} = 0.92 > 0.47 \qquad \leftarrow \frac{57000\sqrt{5000}}{1000}$$

OK ✓

(4) Designing a prestressed girder

3 Double tee point loads on a girder

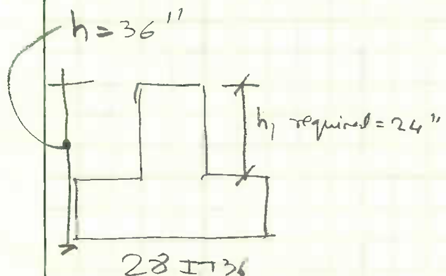


Loads

Factored P = 3.24 $\frac{k}{ft}$ × 27.6' = 89.4k per member

Total Superimposed Service load = (62.7 + 74) + 100 = 236.7 psf

here as total depth of double tee is 24",
we want depth of web of inverted tee beam to be 24" to align top of slab with top of beam.



From PCI Design Handbook
selecting an inverted tee beam

Required span = 27.6' ≈ 28'

Re Superimposed service load = 236.7 × 27.6'
= 6532.9 plf

h_1 = 24" or greater

So, $h = h_1 + h_2$, $h \geq 24$

and Using Normal weight concrete

Try 28IT36

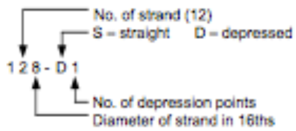
Span 28' ⟶ Superimposed load capacity = 7075 plf > 6533 plf
OK

Requires 168-S strands.

$$\Delta_{LL} = \frac{5wl^4}{384EI} = \frac{(5)(2.76)(27.6)^4(12^3)}{(384)(4030\text{ ksi})(68{,}101)} = 0.13 < \frac{l}{360} = 0.92$$

OK

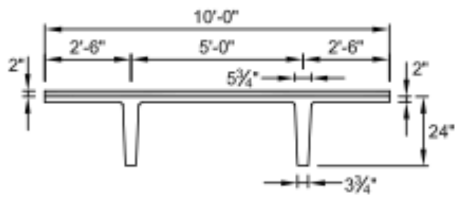
Strand Pattern Designation



Safe loads shown include dead load of 10 psf for untopped members and 15 psf for topped members. Remainder is live load. Long-time cambers include superimposed dead load but do not include live load.

Key
179 – Safe superimposed service load, psf
1.0 – Estimated camber at erection, in.
1.3 – Estimated long-time camber, in.

DOUBLE TEE
10'-0" x 24"
Lightweight Concrete



$f'_c = 5{,}000$ psi
$f_{pu} = 270{,}000$ psi

Section Properties

	Untopped		Topped	
A =	449	in.^{2}	—	
I =	22,469	in.^{4}	31,515	in.^{4}
y_b =	17.77	in.	20.53	in.
y_t =	6.23	in.	5.47	in.
S_b =	1,264	in.^{3}	1,535	in.^{3}
S_t =	3,607	in.^{3}	5,761	in.^{3}
wt =	359	plf	609	plf
DL =	36	psf	61	psf
V/S =	1.35	in.		

10LDT24

Table of safe superimposed service load (psf) and cambers (in.) **No Topping**

Strand Pattern	y_s(end) in. y_s(center) in.	Span, ft																									
		30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80
68-S	4.00	179	155	134	117	103	90	80	70	62	55	49	43	38	34	30	27										
	4.00	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.5										
		1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.8	1.8	1.8	1.7	1.6	1.5	1.3	1.0	0.6										
88-S	5.00			175	154	136	120	107	95	85	76	68	61	55	49	44	40	36	32	29	26						
	5.00			1.6	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.6	2.6	2.6	2.6	2.5	2.4	2.3	2.1						
				2.0	2.2	2.3	2.4	2.5	2.6	2.7	2.7	2.7	2.7	2.6	2.5	2.4	2.2	1.9	1.6	1.1	0.6						
108-S	6.00				185	164	145	130	116	104	94	84	76	69	62	56	51	46	42	38	34	31	27				
	6.00				2.0	2.1	2.3	2.5	2.6	2.8	2.9	3.1	3.2	3.3	3.3	3.4	3.4	3.4	3.4	3.4	3.3	3.1	2.9				
					2.5	2.7	2.9	3.0	3.2	3.3	3.4	3.4	3.5	3.4	3.4	3.3	3.2	3.0	2.8	2.5	2.2	1.7	1.1				
128-S	7.00										108	98	87	78	70	63	57	51	47	42	39	35	32	29	26		
	7.00										3.2	3.4	3.5	3.7	3.8	3.9	3.9	4.0	4.0	4.0	3.9	3.9	3.7	3.6	3.3		
											3.9	4.0	4.0	4.0	4.0	4.0	3.8	3.7	3.5	3.3	3.0	2.6	2.2	1.6	1.0		
128-D1	11.67																72	65	59	53	48	43	39	35	32	29	27
	3.25																4.5	4.6	4.7	4.8	4.8	4.8	4.7	4.5	4.3	4.0	3.7
																	4.7	4.6	4.4	4.2	3.9	3.5	3.0	2.4	1.7	1.0	0.2
148-D1	12.86																						47	43	39	35	31
	3.50																						5.6	5.6	5.5	5.4	5.2
																							4.5	4.0	3.4	2.8	2.0

10LDT24 + 2

Table of safe superimposed service load (psf) and cambers (in.) **2 in. Normal Weight Topping**

Strand Pattern	y_s(end) in. y_s(center) in.	Span, ft																		
		30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66
68-S	4.00	181	154	131	113	97	83	72	62	53	45	38	32							
	4.00	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.7	1.7	1.7							
		1.0	1.1	1.1	1.1	1.1	1.0	1.0	0.8	0.7	0.5	0.2	−0.1							
88-S	5.00			177	153	133	116	101	89	78	68	59	51	43	35					
	5.00			1.6	1.7	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.6	2.7					
				1.6	1.6	1.7	1.7	1.6	1.6	1.5	1.3	1.1	0.8	0.5	0.1					
108-S	6.00				188	165	144	127	112	99	87	75	63	53	45	38	32			
	6.00				2.0	2.1	2.3	2.5	2.6	2.8	2.9	3.1	3.2	3.3	3.3	3.4	3.4			
					1.9	2.0	2.1	2.1	2.1	2.0	1.9	1.8	1.6	1.3	0.9	0.6	0.1			
128-S	7.00										102	88	76	65	55	46	39	33		
	7.00										3.2	3.4	3.5	3.7	3.8	3.9	3.9	4.0		
											2.4	2.2	2.1	1.8	1.5	1.1	0.6	0.1		
128-D1	11.67																57	49	41	34
	3.25																4.5	4.6	4.7	4.8
																	1.4	0.9	0.3	−0.4

Strength is based on strain compatibility; bottom tension is limited to $12\sqrt{f'_c}$; see pages 2–7 through 2–10 for explanation. Shaded values require release strengths higher than 3500 psi.

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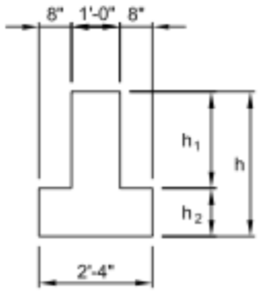
INVERTED TEE BEAMS

Normal Weight Concrete



f'_c = 5,000 psi
f_{pu} = 270,000 psi
½ in. diameter
low-relaxation strand

Section Properties								
Designation	h in.	h_1/h_2 in./in.	A in.^{2}	I in.^{4}	y_b in.	S_b in.^{3}	S_t in.^{3}	wt plf
28IT20	20	12/8	368	11,688	7.91	1,478	967	383
28IT24	24	12/12	480	20,275	9.60	2,112	1,408	500
28IT28	28	16/12	528	32,076	11.09	2,892	1,897	550
28IT32	32	20/12	576	47,872	12.67	3,778	2,477	600
28IT36	36	24/12	624	68,101	14.31	4,759	3,140	650
28IT40	40	24/16	736	93,503	15.83	5,907	3,869	767
28IT44	44	28/16	784	124,437	17.43	7,139	4,683	817
28IT48	48	32/16	832	161,424	19.08	8,460	5,582	867
28IT52	52	36/16	880	204,884	20.76	9,869	6,558	917
28IT56	56	40/16	928	255,229	22.48	11,354	7,614	967
28IT60	60	44/16	976	312,866	24.23	12,912	8,747	1,017

1. Check local area for availability of other sizes.
2. Safe loads shown include 50% superimposed dead load and 50% live load. 800 psi top tension has been allowed, therefore, additional top reinforcement is required.
3. Safe loads can be significantly increased by use of structural composite topping.

Key
6511 – Safe superimposed service load, plf.
0.2 – Estimated camber at erection, in.
0.1 – Estimated long-time camber, in.

Table of safe superimposed service load (plf) and cambers (in.)

Desig-nation	No. Strand	y_s(end) in. y_s(center) in.	Span, ft 16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
28IT20	98-S	2.44	6511	5076	4049	3289	2711	2262	1905	1617	1381	1186	1022							
		2.44	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7	0.8							
			0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	–0.1							
28IT24	188-S	2.73	9612	7504	5997	4882	4034	3374	2850	2427	2081	1795	1555	1351	1178	1029				
		2.73	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8				
			0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	–0.1	–0.2				
28IT28	138-S	3.08			8353	6822	5657	4750	4031	3451	2976	2582	2252	1973	1735	1530	1352	1197	1061	
		3.08			0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.9	0.8	0.8	
					0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	–0.1	–0.2	–0.2	
28IT32	158-S	3.47				9049	7521	5333	5389	4628	4006	3490	3057	2691	2379	2110	1876	1673	1495	1337
		3.47				0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9	0.9
						0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	–0.1
28IT36	168-S	3.50					9832	8295	7075	6092	5287	4619	4060	3587	3183	2835	2534	2271	2040	1836
		3.50					0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	0.9
							0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	–0.1
28IT40	198-S	4.21							8638	7440	6460	5647	4966	4390	3898	3474	3107	2787	2506	2258
		4.21							0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.8	0.9	0.9
									0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
28IT44	208-S	4.40								9186	7989	6997	6165	5462	4861	4344	3896	3505	3162	2859
		4.40								0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8
										0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
28IT48	228-S	4.55									9719	8525	7523	6676	5953	5330	4791	4320	3907	3542
		4.55									0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9
											0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
28IT52	248-S	5.17										9987	8823	7838	6998	6274	5647	4100	4619	4196
		5.17										0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.8
												0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
28IT56	268-S	5.23												9307	8319	7469	6731	6088	5524	5026
		5.23												0.5	0.6	0.6	0.7	0.7	0.8	0.8
														0.2	0.2	0.2	0.2	0.2	0.2	0.2
28IT60	288-S	5.57													9645	8668	7820	7081	6432	5859
		5.57													0.6	0.6	0.7	0.7	0.8	0.8
															0.2	0.2	0.2	0.2	0.2	0.2

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