BUILDINGS AS INTEGRATED SYSTEMS
A Structurally and Mechanically
Integrated Prefabricated Two-Way
Concrete Structural Floor-System

by

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Signature of Author

Certified by

Accepted by

Department of Architecture, Jan 1967
Thesis Supervisor
Dean of the School of Architecture and Planning
January 19th 1967

Dean Lawrence B. Anderson,
School of Architecture & Planning,
Massachusetts Institute of Technology,
Cambridge, Mass. 02139.

Dear Dean Anderson,

In partial fulfillment of the requirements for the degree of Master of Architecture, I hereby submit this thesis entitled: "A Structurally and Mechanically Integrated Prefabricated Two-Way Concrete Structural System".

Respectfully,

Istvan Mezes
Section 1

1.0 THE SYSTEM

1.1 General Description

The project attempts to develop a series of components from which various buildings of a given type can be constructed. These buildings will share a common range of structural spans, mechanical equipment, required exit distances, degree of fireproofing and ability to resist loads. The buildings will differ in size, shape and specific mechanical services.

The group of components, or system, developed for this project fulfills the specific needs of a Branch University in an urban location at the N.E. part of the U.S.A. The buildings can similarly be used for other academic buildings, research laboratories and some office facilities. The general idea is to develop a system which will be capable of maximum internal rearrangement when the need arises, to develop a kind of anonymous architectural envelope within which the functions of such academic institution can freely be changed, or relocated without any structural alteration. The system provides space mechanically serviced with air-supply, air-return, lighting, piped services and vertical circulation.
1.2 Division of Space in the Horizontal Plane

Space in the horizontal plane is limited by 6'-5" square columns occurring on centers of 63'-0" x 63'-0", and cores, (containing fire-stairs, male & female washrooms, elevators, janitor closets, vertical shafts, etc. of needed areas) at intervals not exceeding by-law regulations. Space can be subdivided by movable partitions placed anywhere along a grid of alternating dimensions of 3'-0" and 6'-0". The smallest horizontal area which can be created and reached by all the mechanical services is 6'-0" x 9'-0".

The 3'-0" & 6'-0" alternating grid system allows varied spacing of partitions, e.g. it is possible to have offices spaced side by side at every 9'-0" center. Another arrangement is the placing of offices side by side in an alternating dimension of 9'-0" and 12'-0" widths. A third increment in width shows partitions at an alternating dimension of 15'-0" & 12'-0", or 15'-0" & 9'-0", or in many other variations thereon using 9'-0", 12'-0", 15'-0", 18'-0", 21'-0", 24'-0", etc. This partition-layout can fulfill any possible variations of the varied requirements any problem may need, without jumping too large dimensions for the next grid.

The system is infinitely extendable in the horizontal plane.
in any direction, and can grow in the increments of full bays, or by the remaining portions between full bay dimension and cantilevers of previous stages. Openings in the construction can be designed in the center of bays, preferably of square shapes between four columns or any length of such openings over many bays, preserving a minimum of 12'-0" cantilever from the center of girders on either side of such openings, to assure structural continuity of the neighboring bays. Cores are designed in such manner as not to exceed this dimension, but to accommodate them within this limit.

1.3 Division of Space in the Vertical Plane

In the vertical plane, space is divided by floors which can be placed at intervals of 13'-6". The floor structure is 3'-6" thick, thus creating normal floor to ceiling height of 10'-0". Large areas of the floor can be omitted without affecting the integrity of the overall structure. This allows considerable freedom in the initial planning of auditoriums, lounges, ceremonial stairways, etc., and in subsequent remodelling of the building to add or modify high spaces. The system allows a maximum building height of five stories, or 67'-6" — though by some knowledge of future
space consideration, in the light of economic forecast (land-value, expansion, density, etc.) the number of floors can be increased to double - excepting of course the doubling of mechanical spaces too (roof-mechanical, etc.).

It is conceivable, that by some re-design of the lower-level columns, let's say up to two stories, the building can be erected up to seven floors, using thicker, and perhaps on-site-cast columns (garages, basement, etc.) without increasing the mechanical space requirements. Floor structure can in any case be the same, irrespective of building height.
2.0 STRUCTURE

2.1 General Description

Two-way structural action is used. Columns rise on centers of 63'-0" x 63'-0". Waffle-slab type elements are used in both girder-part of structure and beams. All elements are prefabricated (in plant, or on-site plant) and are lifted into position by cranes positioned in the structural openings of the building. The elements are linear and are pretensioned in one direction like the beams, or just simply reinforced (girder type B). Girder type A is pretensioned. In the other direction, all elements are post-tensioned, when in place, in open grooves designed in the rib-portion of elements. These grooves, after the post-tensioning is applied, will be filled by cement-grouting to protect cables from corrosion.

2.2 Description of Elements

All of the structural elements are made of precast concrete. Shapes were chosen to describe the two-way action, which yield high structural efficiency, easy to transport and erect.
The floor-structure consists basically of three different elements: two girder types (one of which may have different lengths depending upon whether it is in the interior zone, or at the perimeter doing cantilever work of varied dimensions), and one type of basic "infill" beam, the size of which is constant. (60% of bay area)

It is considered, that though girder B's dimensions are not constant, they differ only in length, thus the same formwork can be used to produce all lengths, by blocking the formwork as needed.

Girder A is the same length as the infill-beams—though it differs in its physical dimension, reinforcing and its sections. It is important to note, that serious consideration was given to the number of elements composing the system, relative to formwork, etc. In fact, even if the system were able to use exactly the same elements, and there would be only one such shape, considering the erection-efficiency, it would still be necessary to fabricate numerous pieces, of exactly the same formwork, to satisfy the daily output for such a huge project. For small projects, perhaps other design would fit better—though again this would be a matter of very close study.
The price of formwork over so large a number of elements is irrelevant in the scope of this study, especially if we consider that these same forms can be used over and over again.

An interesting comparison can be made of the advantages of the two-way and one-way systems. The former can be criticized, from an economic point of view, of having a higher ratio of dead-load over the live-load, which perhaps is inevitable with such a system, though from a structural point of view it is conceivable that since all major forces are distributed in two directions, compressive stresses too are two-directional - thus using light concrete in the infill beams, at least this ratio can be efficiently lowered, at which point this argument becomes weak in relation to the other properties of a two-way system. From a safety point of view, it is a much more reliable structure, not discussing its architectural merit applied to this study, which is ultimately to provide an anonymous kind of structure, with no restriction of direction, etc.

**Infill Slabs** of 3'-0" wide x 3" thick x 6'-0" long, with bevelled edges complete the prefabricated portion of the floor structure. These sit in the grooves of the elements to fill the space between them. These infill slabs contain the necessary circular openings, temporarily blocked
by wood or concrete "corks" to accommodate piping connection to the 3'-0" wide shafts below. 2" topping is cast over the whole area, levelling the floor to protect surface-tension bars, and to house the electrical and telephone communication system where needed.

To express the build-up of forces in the ceiling, both from an aesthetical and structural point of view, the ribs are shaped so as to widen near elements of higher structural degree (girders) giving a pleasant transition from thin (5") ribs of the infill beams, to the 10" wide members of the girder diaphragms.

The prefabricated columns are cast in 12" thick x 6'-5" wide, and 11'-0" high sections, with details at the upper and lower ends to receive the first girder element. Standard, deformed reinforcing bars project out at both ends, to be welded to next column's reinforcing. This portion is located at the thickness of floor-construction, with ample space for latter on-site concrete work, to protect welded bars and give continuity in the vertical direction to columns. Work-gaps are provided between precast and cast-on-site portion to minimize colour-differences of the two.

Girder B is a waffle-slab-like element, similar to infill beam, but two of its ribs on either side of the center line, are designed in such a way as to be able to act as girder
element via post-tensioning. The girder portion is an integral part of this element. It is cast to accommodate the bearing of the on-coming infill beams, by way of "seats" at its ends.

**Cantilevering.** The whole structural system is based on the use of cantilever and infill-beam principle, which makes use of load-distribution in a more economical manner. This cantilever principle is inherent and obvious from the drawings. The system is capable of a maximum 24'-0" cantilever from the column centers (or 3'-0" to 6'-0" modular growth, for edge-condition). No particular problem arises at such condition in one vertical section of the structure (parallel to beams). Girder B's size solves this.

In the other section for an edge condition this is not so obvious. Similar cantilever design to above can still be achieved by placing beams perpendicular to the uncantilevered portion of floor-system, providing that in each case the girder ribs will be part of such cantilevered elements. (Replacing Girder A in this case.) The reinforcement of this element will be similar to the idea shown in the interior zones. (Surface reinforcement for taking up negative moments.)
Reinforcement Techniques. Infill beams are reinforced with high-tensile cables (100,000 p.s.i.) while prefabrication in process. In addition they contain ordinary reinforcing bars or mesh, according to the use and location.

Girder A has a strand of high-tensile cable, to take up positive bending moments, bent-up near supports according to the principles of pretensioning - plus ordinary reinforcing steel similar to infill-beams.

Girder B has only ordinary reinforcement, having no special length or need.

When gaps between infill and Girder B are grouted, the structure may be made to behave like a continuously supported beam. By applying the surface post-tension technique proposed (for assurance of ultimate continuity between elements) any number of beams (and girders) composing the width (or length) of such structure becomes nearly one homogeneous, continuously-supported beam system. Thus surface post-tension will take care of the negative bending moments, characteristic of such beams. This surface-post-tension proposed makes it possible to apply the necessary strain on the structure at the length where it is needed. The amount of force that is required - without special provision in the precast element to accommodate such.

It is a more convenient way to post-tension, than e.g. leaving out holes in the precast and worry for precise grouting, plus the bother, organization and problems of how to solve such process. The post-tensioned portions of this system are such
as always to see the cables, and to do more reliable grouting, or filling of grooves, than otherwise would be possible.

It is inconceivable for example that a cable running through hundreds of feet in the holes of a structure could be perfectly filled from the ends. No grouting system is so reliable as to expect such perfection. A mistake or air bubble could cause fatal consequences.
2.3 Elements

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<th>Name</th>
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<th>Length</th>
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<td>11'-0&quot;</td>
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<td>3'-2&quot;</td>
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<tr>
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<td>waffle-slab</td>
<td>6'-5&quot;</td>
<td>3'-2&quot;</td>
<td>18'-0&quot;</td>
<td>14-18 K</td>
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2.4 Erection Procedure

1. Column-elements are lifted, levelled and stabilized.
2. Scaffolding erected along the line of girder B between columns in two rows near the end of these.
4. Placing of girder A and infill beams begins, placing them at ends of girder B. No scaffolding necessary.
5. Infill slabs placed and grouted to top.
6. Surface post-tension bars welded, pulled together for tensioning and fixed.
7. 2" topping poured.
8. Post-tension cables placed at grooves, at bottom of all ribs, and tension applied.
The structure now is complete. Additional erection steps involve placement of mechanical equipment and are described in the next section.

3.0 MECHANICAL EQUIPMENT

3.1 General Description

Mechanical services rise within the structural columns on centers of 63'-0" x 63'-0". Main horizontal distributors contained between the girder portion of element B. The mechanical service is completely self-contained. Each column serves an area of full bay size. Cores, though are designed to have vertical shafts, for mechanical ducts and piped services. Their use is basically to serve specific functions or areas of buildings with other than normal services (e.g., laboratories, etc.). Supply and return air is fed from the columns into opposite ends of each main distributor. Secondary distributors are contained between the web of adjoining infill beams. They occur on centers of 9'-0" and are 30'-0" long. Secondary distributors are arranged in alternating supply and return manner, though as for piped services, each module of 9'-0" contains the possi-
bility of such servicing. For a full complement of mechanical services, a space must cut across only a distance of 9'-0" in each direction. The mechanical layout also is two-way. From the secondary distributors there is a possibility to serve the space in a perpendicular direction to the secondary. This solution makes it convenient to cut off zones of varied areas and allow more irregular zoning design if needed. The mechanical module is the same as that of the structure, and follows a similar pattern of growth. Thus whatever extensions or voids are possible within structural limits, can be mechanically serviced, without special conditions or awkward pattern of distribution.

3.2 Air Supply

High-velocity, single-duct system, with re-heat coils. Cold air rises at high velocity through vertical ducts. At each floor level air is taken off on either side of column, into an attenuator where the velocity is lowered and sound-energy attenuated. A main horizontal distributor extends from the attenuator, from which a maximum of five distributors are served. Each of these distributors can be fitted with an electric re-heat coil, to provide individual temperature control to zoned areas. The secondary and consequent distributors serve the double function of air-duct and strip diffuser. Where
they meet an exterior wall, these distributors supply induction units which further heat and cool the air by passing it over coils containing hot or cold water.

Each secondary distributor contains an electric (or hot-water) re-heat coil close to the junction of primary duct. When temperature in zone reaches an unspecified level, electric thermostat located on partitions automatically set these re-heat coils till desired temperature is obtained. Electric sensors, located at the vicinity of return grills give a signal to thermostats to start or close action. It is considered that each space designed will have one such thermostat located on a wall which will be most unlikely to move at a later date, thus obtaining independent space control for each room. Due to the mechanical two-way action, there is an almost unlimited possibility to design any size, or shape zones. Even when zones are "stacked", one behind the other (relative to primary ducts). The back-zones can be serviced by the next secondary branch fitted with its own re-heat coils. Expecting such possible variations in serviced areas, the secondary ducts could be slightly oversized for such events. The cost of this (which cannot amount to much) may easily be worth considering the flexibility obtained.

All ducts run in the 3'-0" module width, where they are more inconspicuous. There is more than enough dimension between
the concrete beam to accommodate their installation joining and other manipulative requirements. (Service change, etc.) The system can, with small modification, be more "elegant" (mechanically speaking). The large attenuators which are shown on either outlet of column may not be the most fortunate solution. It creates space problems, takes up a large area by its sheer size, and gives difficulty in placing standard lighting fixtures in these particular waffles. Alternative can be solved more elegantly in the primary ducts. (Information obtained at a later date of the design process.)

3.3 Air Return

Follows the same principle as the supply and is also alternating layout.

3.4 Piped Services

Piped services include electrical conduit, communication lines and roof drains, as well as hot and cold water supply and return for random sinks, and re-heat re-cool coils of the perimeter air system. These services rise within the vertical column and are distributed throughout the 3'-0" service-module in the horizontal plane.
By punching out the particular "cork" in the infill slabs, connection to equipment above can be established.

All four vertical mains (hot & cold water, 6" waste, 3" vent) in the column are placed on one side only, though these services cover one full bay dimension similar to the air-handling system.

The "primary" line of the waste-pipe is 4" and so are the consecutive branches, having a slope of \( \frac{1}{4} \)" for every 12". All services above are designed so that they by-pass the girder B portion of the structure, which is well taken over by the air-primers.

All of the vertical and horizontal pipes are accessible and may be readily serviced and replaced.

3.5 Lighting

Possible arrangement of light-fixtures is as follows:
Lighting is provided in each 6'-0" size square. A 3'-0" x 3'-0" square-shaped acrylic plastic fixture, with 4-60 W. tubes is placed close to the bottom of each coffer (to light the sides of the ribs as much as possible in addition to providing a 100 candle light-value on a horizontal plane 3'-6" from floor. Within the normal cone of vision, no fixtures can be seen. Though these fixtures are on a 9'-0" center, to
center dimension, the fluorescent tube placement in each is divided along the 3'-0" width. Thus the actual distance between two fixtures is more favourable and is about 7'-0".

A different arrangement of fixtures shows fixtures placed in the service module too (in addition to the square ones) for a higher degree of illumination and, or, a desirable ceiling-illumination effect.

Spot-light (incandescent) can be placed in the 3'-0" square position of the service module (either alone or in complement of the above types).

3.6 Acoustics

All waffle-slab elements of the system are cast so that a "built-in" tectum surface is placed on the formwork before casting the concrete of each waffle or coffer. By casting the concrete this surface will be in level with all surfaces. Since there are no openings in the large square module, the only place for sound to travel from one room to the next is through the service module.

The system gives solution in the following manner to take care of this:

a) to block openings of these modules only above partitions, between neighboring rooms. This is an economical and
good solution, even though care should be exercised
in its execution. (Shaping of duct and pipes) Still
the amount of work involved is far more competitive
to other thoughts, which would attempt to design the
structure in such a way as to give an over-importance
to this detail, and which for this reason, would per-
haps be more expensive. The larger the rooms compari-
tively, the less openings are involved per square foot
of space. Material for this work may be of heavy
plaster, always cast on the center of such ribs, leav-
ing the edges of openings readable.
Around pipes and ducts there should be at least a thin
(styrofoam?) ring (or gap between pipes and cast-divi-
ders) to allow contraction of these elements.
b) The second solution involves an acoustical panel of
heavy quality, to be placed on the "ears" of elements,
which would cover the service-channel from the bottom,
made from slab pieces that fit over these and can
easily be removed for service-changes.
Though this solution offers an absolutely closed system,
its economical implications are apparent unless one con-
siders the following:
Its use can be justified in smaller rooms, or spaces
where a higher degree of aesthetic quality should be
preserved. (No pipes, ducts are visible.)
Also this solution offers a very interesting thought: With such treatment, the return-ducts as such could be eliminated using the full size of the service channels as plenum. This system would be capable of a substantial saving in ducts, and return-air grills which in turn would result in a simpler and more sophisticated design. This proposal could be the object of a closer economical study. Theoretically it seems to make good sense, and can't be far-fetched from the aims of this project.
Buildings as Integrated Systems

Section 2
Subject: An Urban University

Location: N.E. part of the U.S.A., in a city comparable in size and population to Boston and its outlying community of Cambridge.

The actual site is abstract and fictitious, and bears no similarity to any existing location; the idea being to develop a model for such Institute, rather than solve a situation given by particular circumstances.

The Expansion:
The underlying theme of the project is expansion. Hence the resulting composition, which I hope expresses this fact, while still preserving the qualities of ultimate completion at every stage.

The site is suggested to be of 65 acres when fully developed, though for better land-economy and management-policy, large portions of this land could be utilized until it becomes required by the Institute. The land can be bought-up by large enough chunks as expansion commences.

It is suggested, that the first stage of development will provide facilities for 5,800 students, and later this number may rise up to 12,000 either by a full-scale second stage construction, (see program) or which is more likely in the
scope of such Institute, by gradual step by step process as the need arises.

A self-imposed criterion for successful solution, includes to design and compose the layout of the functions in such way as to facilitate expansions of any size and module, without disturbing the normal work of the Institute at any time.

For this reason, expansion will not occur vertically, that is to say, over or on top of previous stage developments, but only on separate new blocks of construction.

Any new addition will be a fully completed block, of at least 5-6 floor heights (for mechanical reasons) and is contemplated that due to this reason, the new addition will always be a reasonable and economical construction-volume.

As a further measure for ultimate efficiency and economy, portions of the garage (which is built with a 14'-0" height) could also be utilized for academic use before or during the time, while a new addition may not be a very economical proposition yet, but there is a pressing need for space. The loss of garage-space may be easier to redeem, with nearby accommodation than academic functions.

SITE-CONDITIONS

The lot is in a neighborhood where low-density housing and light-industry are situated at present. It is assumed that upon and during completion of the Institute, this picture may change drastically, drawing more sophisticated functions.
to the area around. The lot is practically flat. With this in mind, it is assumed that streets around the University will shape into the following uses:

The North-street may develop into a residential neighborhood of apartment-block quality.

The East-street — where the University housing is situated (about 3,000 students) will be as above, but mixed with light commercials (stores, groceries, etc.) and high-rise apartments.

The West-street will be occupied by apartments as in East-street plus some commercials of higher-grade.

The West-street — which can be compared to Massachusetts Avenue can be expected to develop into public-buildings, department stores, offices and the like, of high density.

THE CIRCULATION:

The lot at the final stage of development will measure 1,250' x 2,330'. Had the regular city blocks of about 300' x 300' occupied this area, it would mean the absence of at least 7 blocks by 4 blocks, of previous city functions.

To assure physical continuity from the neighboring streets, to the complex, both for vehicular and pedestrian traffic, the design incorporates entrances to the site at numerous points.

VEHICULAR ENTRANCE: There are at least three entrances for vehicles on each of the two larger sides of the lot.
(North and South streets) one entrance from the main street
(West) compared to e.g., Massachusetts Avenue and M.I.T.,
and some five entrances on the other shorter side, (East)
where the housing is situated.

The garage space is well vented and lighted by sporadic
placing of openings in its ceiling-slab. Provision is given
for convenient and easy access to and from garage. Due to
the nature of project, the entrance will act a double func-
tion of entrance and exit (morning fill-up — entrance; eve-
n ing: exit).

THE PEDESTRIAN CIRCULATION: There are numerous entrances to
the University for the pedestrian — in fact, each block or
new addition contains its own access to streets. There are
three major entrances to the major space from three different
streets. One of them (the South one) has been elected to be
the Main-entrance, or Ceremonial-entrance to the Complex.
Though other entrances too are capable of this function, the
choice was made from a convenience point of view; its en-
trance being the shortest distance to the street.

VERTICAL CIRCULATION: Cores serving as stairs, elevators
and toilets are spaced within the Complex, according to ex-
isting by-laws and regulations. Maximum height of all Aca-
demic functions (except Student Center and Library) is five
levels. For this reason, it is contemplated that a large
number of the elevator-cores could be replaced with escal-
lators leading from the Main-level to the 3rd level,
suggesting, that from here on up to the 5th level, students would walk up, thereby saving substantial expenditure in elevator costs.

THE DESIGN CONCEPT:

This is based on system studies pursued in the first semester, and follows the concept of a two-way structural action, as described in Report 1. The design concept thus reflects in its details, approaches outlines, and hopefully in every aspect of its composition, its derivatives, giving great importance for successive staging and expansion. The general plan may be compared to an amoeba-like shape, free with no definite or particular definition, though a central portion is detectable, from where almost free-floating elements, or arms, extend in many directions, expressing its structural concept. While this freedom of movement is seemingly uncontrolled, one may read the conscious desire for a finally-controlled composition. The strong spine, along the longitudinal direction, is one such decision and shows a predetermined path the design process will follow - and was strictly subjective. This was also the beginning of the design theme and the continuation of the architectural exercise. This spine-axis, like a multi-coloured bead, contains a sequence of spaces that are joined one after the other, further accentuated by other like-elements, linked and joined to it on a diagonal axis.

5.
The culmination of spaces occur in the meeting of the two main axes which hold the three main entrance-points to the university, and which is approximately in the Center of Gravity of the project.

This main (enclosed) space is the "heart" of the Institute. This is where the majority of students arrive from the outside, pass through most frequently, either by going to their classes, shopping at the COOP on the Main level, or passing through enroute to the theatre, auditorium, sporting activities, or mainly for the Dorms. This Central Hall is 2-3 floors in height, is enclosed, and gives sufficient importance and elegance to its function.

The Main level also contains the exhibition-space, so that students simply have to be involved with the latest gimmicks of the arts while passing through.

Above the Central Space, the building contains the functions of Student Center and the Main Library, Cafeteria and other social functions there may be.

All other academic floors are physically connected to each level of this Central Function, thus the movement of students at all times is the shortest possible to this vital area.

Also noteworthy is the fact, that one can reach any given point of the Complex from any other one, without the need to leave the enclosure of building.

Every entrance to the Complex has been architecturally well articulated, leaving no doubt where an entrance might be found.
Every effort has been made for giving worthy importance to these points. Though none of these entrance points is similar in concept; each has its own character.
The academic functions surround the Central Building, and have the potential to expand in any direction.

HOUSING:
There are four tower-structures of at least 30 floors height, and a large number of terraced units along the East side of the lot. The latter ones serve to house the married students, with children, while the towers are used by the undergraduates, graduates and married students without children.
It is expected, that being an Urban University, a large majority of students will use the neighboring facilities for housing. From a design point of view, the small scale of the terraced housing would be more appreciated, and perhaps less disturbing by its contrast to the academic scale, had the neighboring houses been shown. As is now, there seems to be an abrupt change of scale in absence of neighborhood.

SPORTING FACILITIES:
These are located between the housing and the academic buildings - making it easy and convenient to approach from each.

PARKING ON GRADE: According to the program, there are several on-surface parking facilities at the proximity of entrances for visitors. This can be enlarged, depending on requirements. There is plenty of reserved space, both for academic and parking expansion.
Longitudinal section

Cross section

Reflected ceiling plan

Upper view of structure

Structural Elements & Details

MASTER OF ARCHITECTURE
MIT FALL 1966
ISTVÁN MEZÉS
GIRDER REINFORCING DIAGRAM

MID-SPAN BEAMS

STRUCTURAL ELEMENTS & DETAILS