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A PROPOSAL FOR UTILIZATION OF VAULTS AS FLOOR-SLAB STRUCTURES IN CONTEMPORARY ARCHITECTURE

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Abstract: *Vaults are among the oldest known engineering structures, and have escorted the history of architecture through thousands of years. Nowadays, construction industry rarely uses them, and doesn't consider them as a general option to be used for floorslab structures, although they offer several opportunities. The presentation aims to re-introduce vaults into everyday usage, emphasizing their efficient shape, building technology and aesthetic values.*
The following aspects are featured in the paper:
-mathematical definition of vaults,
-main technical terms considering vault constructions,
-main features of the statics of vaults,
-connection of the force-trajectory and the central core,
-importance of shape for ideal material distribution,
-a proposal for a contemporary floorslab structure featuring beams and narrow vaultzones,
-pros and cons of the proposed floorslab structure

Keywords: *Vaults, Concrete, Non-reinforced concrete, Prefabrication, Ecological structures, Vault slabs*

1. INTRODUCTION

The history of architecture and the history of engineering solutions have developed numerous structures to cover areas, rooms and halls. One of the oldest methods to cover large areas are vaults: different eras and cultures developed several shapes and styles, however the main concept remains the same all along:

a shell structure with pure compression in all it's cross-sections.

1.1 Historical examples:

-One of the first known utilization of vaults were in Assyria, where they used them to cover the sewer systems of large cities[1]. The shape of the vault was close to a parabolic shape, this indicates that they made empirical experiments which resulted in this specific shape. The tilted method of the masonry work made construction faster, because it didn't need a framework: each section rested on the previous ose.

Later, in the period of the Roman Empire, vaults were everyday structures for viaducts, thermas and basilicas. Romans used semi-circle vaults.

The Sassanid Empire's famous city of Ctesiphon have already used a major improvement of vaults: they used a parabolic shape instead of a half circle at the palace of Taq Kasra.

Later, gothic architecture and triangulation also tried to find a perfect shape for vaults, which was also close to a parabolic curve.

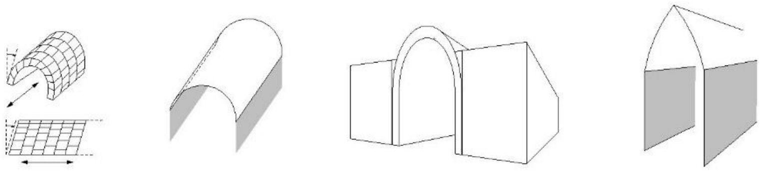

Figure 1.: Historical examples *(author's drawings)*

The main goal of this paper is to show an option for utilization of vaults in contemporary architecture as floor-slab structural elements, both as standard and representative structures.

The main idea is to show the importance of shape in monolithic – non reinforced – concrete vaults, and how tio incorporate them into slab structures.

The paper has no intention to further analyze and present historical methods and shapes of different types of vaults, since this topic is already well researched and documented in the technical literature of the subject. The following works (including but not limited to) cover this topic:

-Szentkirályi-Détshy: The short history of acrhitecture , Bp, 1959, Műszaki könyvkiadó

-Wilfried Koch: Styles of architecture, Poland., 1996, ISBN 8371292880

-David Stephenson: Heavenly vaults, 2009 Princeton Architectural Press

-Adam Pattantyús-Ábrahám: Domes and vaults, Bp.,2011., TERC Kft.

2. MONOLITHIC VAULTS

In the centre of this presentation are monolithic concrete vaults, which are, technically speaking:

-purely compressed

-single-curved

-1st order shell structures,

which means that their main directrix only has one curvature, and the generatrix is a straight line.

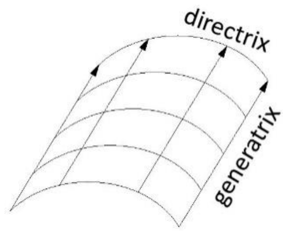

Figure 2.: Geometrical definition of the vault *(author's drawing)*

There are also technical terms in accordance with vault structures:

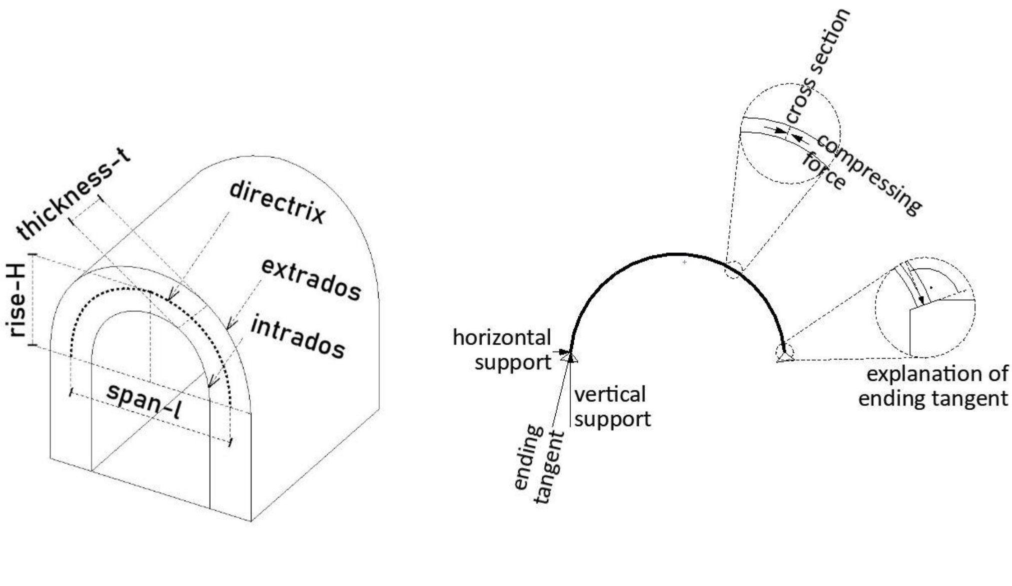

Figure 3.: Technical and statical terms of vaults *(author's drawings)*

The most important feature of vaults are the absence of tension in any cross section, therefore the trajectory of the internal forces is in the focus of designing vaults.

Trajectory of internal forces must always direct to the center of the cross section or it's close vicinity (the central core):

Several factors affect this trajectory:

-self-weight of the vault

-upper loads

-ending tangent

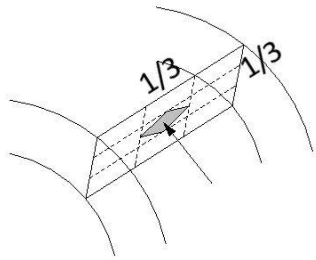

Figure 4.: The concept of central core *(author's drawing)*

The trajectory is formed by the upper loads and the self weight of the vault, and the support forces are always perpendicular to the ending cross section, therefore the ending tangent of the trajectory is a fundamental feature of vault shapes.

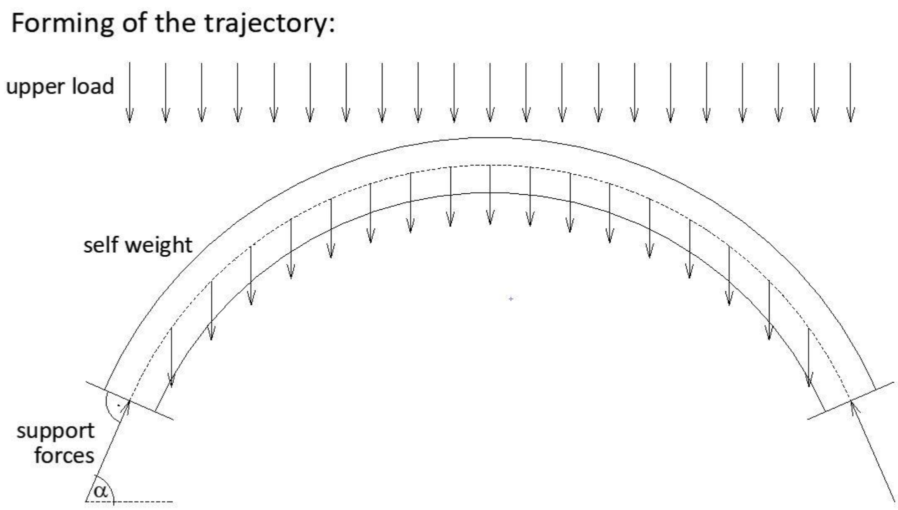

Figure 5.: Forces affecting the trajectory *(author's drawing)*

2.1. Ideal trajectory and shape of the vault

If we want to find the ideal curve for a self-weighted vault for a defined ending tangent (α), we need to draft the curve point-by-point using vector-triangles. The ideal curve therefore is a type of parabola (more precisely a type of cosinus hyperbolicus function).

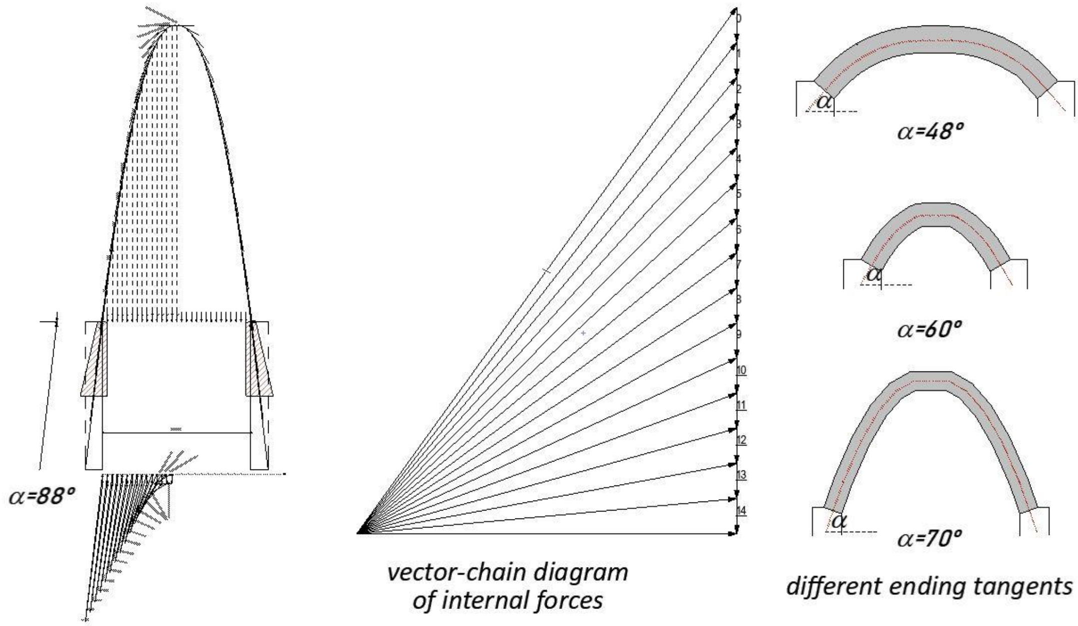

Figure 6.: Drafting method and the vector-diagram for trajectories. Effect of different enging tangents *(author's drawings)*

The ideal curve is a bit modified if we add the upper loads to the drafting, but usually these do not have such a tremendous effect, because the self-weight is dominant over the upper loads. The form of an arch with universal vertical load is parabolic.[2]

However, these findings are not new: an important historical example are the arches in the buildings designed by the famous catalan architect Antoni Gaudí, who used upside-down hanged rope models to find the ideal shapes for arches.

Figure 7.: A typical vault shape used by Gaudí (author's drawing), and a photo from the Casa Mílá [1]

Considering these calculations and draftings, a quite evident question arises: how come, that most vaults are not parabolic shaped?

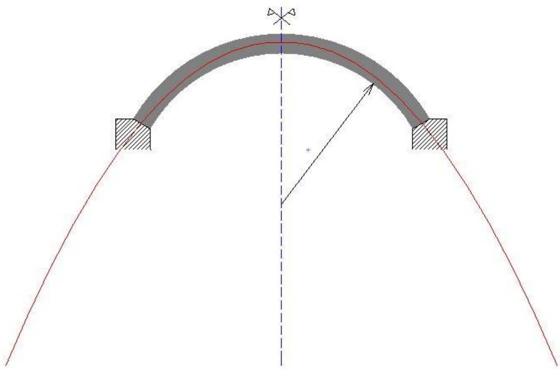

Figure 8.: An ideal vault shape and a segment curve usually meet each other *(author's drawing)*

The simple answer is that a segment curve (not a full semi circle) can usually finely contain a parabolic arch-segment, and circle-segment arches are much easier to construct.

3. CONCLUSION: THE PROPOSED NEW STRUCTURE

3.1. Contemporary solutions to floor slabs

An important field of building structures are floor slabs, which carry the horizontal loads of almost every house or building. Without floor slabs, no building can fullfil it's function, therefore these stuctural elements – along with walls or columns – embody the largest part of a building's structures.

Usually, in contemporary architecture and structural engineering, we use flat slabs or beam structures, both are primarily bent structures featuring bending momentums to carry verticalloads:

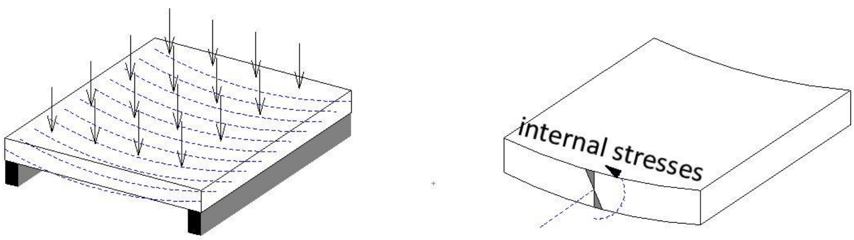

Figure 9.: Typical bent floor slab structues *(author's drawings)*

Bent structures are among the least elegant methods to cover spaces, because bending moments cause large internal stresses, both compression and tension. This means, that strong materials need to be used in order to keep slabs thin, and strong materials (such as steel) use up much more resources.

Using purely compressed or tensioned structures use up much less materials, because compression or tension create far less internal stress inside a given structure.

3.2. Proposition of a new method of thinking to create floor slabs

Let's consider using a beam-reinforced slab, as we often do so in reinforced concrete structures, which means we have main beams and slab zones between the main beams (the beams are the supports of the slab):

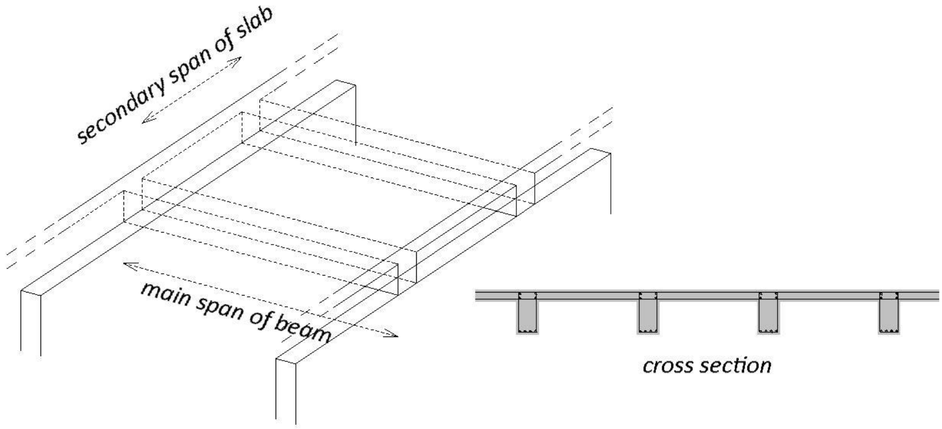

Figure 10.: An often used method to create slabs abowe large areas *(author's drawings)*

This standard floorslab structure of main joists and interfitting plates is nothing new, the same method of thinking was already used from the beginning of architectural history:

using wooden beams and timber planks to create floorslabs is possibly the oldest form of creating additional storeys in buildings.

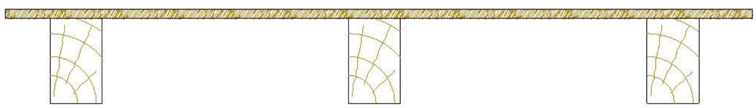

Figure 11.: Wooden beams and timber planking *(author's drawing)*

In the XIX. century, with the advent of steel as a strong and largely available building material, wooden beams were replaced by steel, enabling the construction of wider spans for rooms and larger distances between each beam.[3]

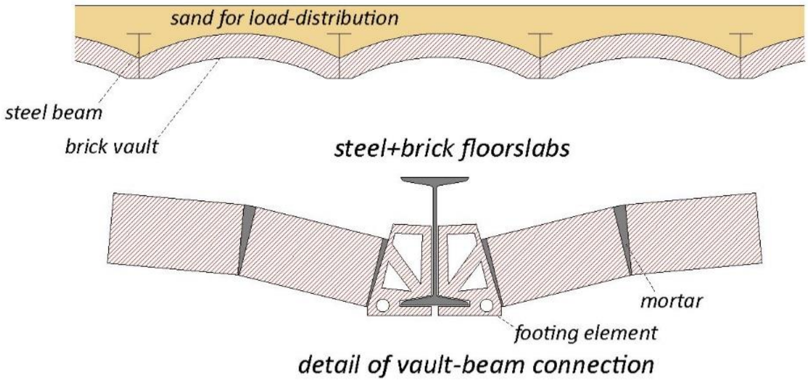

Figure 12.: XIX. century slab type *(author's drawings)*

Now, let's combine the two structure types: reinforced concrete beams and vaults, and create a new type of structure with a combined approach of these two structures:

Let's place concrete vaults between reinforced concrete beams.

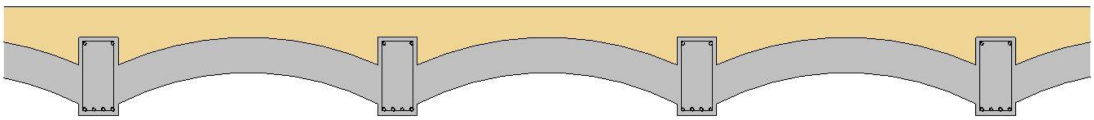

Figure 13.: Proposed new slabtype *(author's drawings)*

Building these types of floor solutions have several advantages, although no method can exist without disadvantages. These are listed here:

<u>Advantages of the proposed new structure:</u>

1. There is no need to reinforce the interfitting zones, only the beams, since the interfitting zones work as vaults between the reinforced concrete beams. Therefore:

-less steel rebars are needed, therefore the structure is cheaper and has a smaller carbon footprint

-less handiwork is needed for the same area of floorslab

-faster to build, since the interfitting zones are only need to be poured, not reinforced

2. This can be a rather subjective argument, but the proposed structure offers a raher exciting architectural surface

Disadvantages of the proposed new structure:

-a more complex framework is needed, but creating prefabricated universal segment-shaped frames can reduce this issue, just as we use standardized framework elements for slabs and beams (for example, 1 meter wide and 1 meter long prefabricated curves)

-since the upper boundary of the vault is also curved, therefore counter framework is needed on the upper side. Just as universal

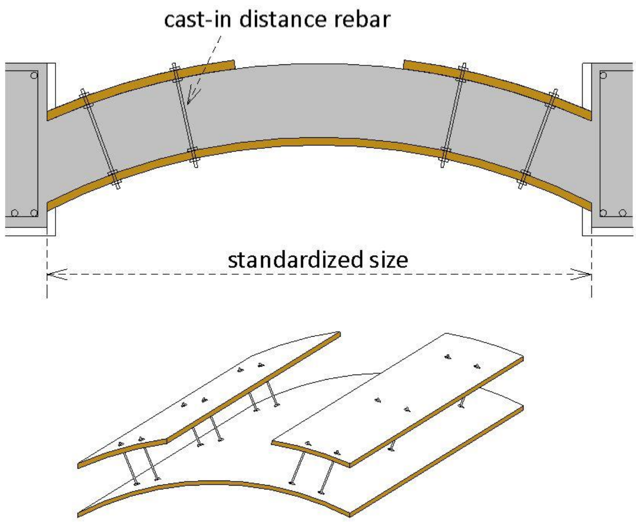

Figure 14.: The required framework for constructioning the beams and the vaults between them *(author's drawing)*

List of photographs taken from the internet:

[1] https://www.rob-tomlinson.com/files/places/zoom-images/casa-mila-la-pedrera-vaulted-roof-space-zoom.jpg

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