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## **Eminent Structural Engineer: Eladio Dieste- Engineer, Master Builder and Architect**

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### **Brief C.V.**

- 1917 Eladio Dieste Saint Martin was born on 10<sup>th</sup> December in the town of Artigas in Uruguay
- 1936 Studies Engineering at the University of the Republic graduating in 1943
- 1944 Starts professional career with Cristiani and Neilson, Norwegian Contractors and the Ministry of Public of Public Works, starts teaching mechanics at the University of Montevideo
- 1947 Collaborates with Spanish Architect, Antonio Bonet, first use of structural brick
- 1955 Forms company Dieste y Montañez SA with Eugenio Montañez, a fellow student from University.
- 1960 The Church of Jesus Christ the Worker completed in Atlantida
- 1979 Completes Warehouse at Montevideo Docks, largest span Gaussian vault, over 45 metres.
- 1993 Dieste begins projects in Spain
- 1995 Dieste retires from the firm
- 2000 On 29<sup>th</sup> July Eladio Dieste dies after a prolonged illness.

### **Introduction**

The Uruguayan Engineer, Eladio Dieste (1917-2000), Fig. 1 encapsulated the essence of the relationship between structure and architecture and as a result was a pioneer in three fields: structures, materials and architecture. He believed in 'resistance through form', the manipulation of geometry to produce apparently complex structures that are actually highly efficient and expressive. He stands alongside the other great designers and builders of the 20<sup>th</sup> century such as Nervi, Candela and Isler. However unlike his European counterparts, and what makes his work particularly remarkable, was his use of brick rather than concrete, in applications that were often easier to construct and less expensive. Dieste sought for a technology that suited the needs of his country. In an essay entitled Technology and Under-development, (Dieste 1996), he wrote: 'I believe that we must contemplate each problem independently, keeping in mind the conditions of our circumstances and environments'. One of these

conditions was the abundant availability of brick, whilst most other construction materials including timber, steel and cement were imported. He sought to avoid reliance on technology and systems from the developed world, believing that these were often expensive and inappropriate for Uruguay. Uruguay lacked material and economic resource but not inventiveness and intuition.

Dieste studied engineering at the University of Montevideo, graduating in 1943 and subsequently formed the company Dieste y Montañez with his friend from university Eugenio Montañez. The company both designs and constructs buildings. Dieste created and developed many structural forms and techniques in brick. Each project was a prototype for the next, allowing the development of a series of typologies that evolved and progressed until he was able to build quite extraordinary structures with confidence and certainty. The output of the company was considerable with over 1.5 million square metres of buildings and structures completed. Three dominant typologies are the Free-standing Barrel Vault, the Gaussian Vault and Towers, used in factories, warehouses, commercial and sports buildings. Some of the individual buildings, such as the Church of Jesus Christ the Worker and the church of San Pedro are considered architectural masterpieces, often without reference to the remarkable structural inventiveness and intuition that is at the heart of their design.

### **Free-standing Barrel Vaults, use of brick and construction practice**

Dieste's first use of brick in structures arose with his collaboration with the Spanish Modernist architect Antonio Bonet on the Berlinghieri House in 1947. Dieste proposed replacing the concrete shell roof of the original design with a thin brick vault. He had to convince the architect that he did not envisage a heavy traditional vault but one of comparable thinness. From this point on he developed a deep interest in the application of brickwork in contemporary structures. He believed that brickwork had considerable practical advantages:

- It is lighter than concrete;
- Over 90% of the material is already hardened when placed and due to the suction of the brick, excess moisture is absorbed causing the mortar to stiffen more quickly. In many of his projects where the formwork was used repeatedly it was often stripped after only 24hrs;
- It uses less cement (imported into Uruguay);
- Brickwork ages well and its hygro-thermal properties can help control internal humidity;

The Free-standing barrel vault was a typology that Dieste perfected through repeated construction and practice, Fig.2. The term 'free-standing' comes from his intention to minimise the vertical support for the vaults. In concrete vaults of the same period it was conventional practice to support the vaults on solid end walls. Dieste developed the form of the vault to provide the necessary stiffness and stability to avoid contact with the end walls and eliminate the use of tie rods. The result is a structural form in masonry that challenges our expectations and understanding of the material. They appear as if they are trying to break free from their supporting columns. The predominant load on the vaults is self-weight, Dieste minimised the self-weight for both practical and aesthetic reasons. The cross section follows the catenary and is always only one brick in thickness. The vaults are relatively deep, typically a span to rise-ratio of 4. The stresses in the brickwork and the thrusts from the vault are therefore

comparatively low. Dieste avoided the use of tie rods by 'resisting through form'. The thrusts are resolved by folding the edge of the vault at the springing points to form stiff horizontal edge beams, again only 1 brick in thickness, these transfer the thrusts to braced concrete columns, eliminating tie rods. Dieste utilised the cross section of the vault as a stiff, deep beam capable of large spans between columns. In the project for an agricultural warehouse, Agro Industry Massaro (1977), five conjoined vaults were constructed with a total length of 115 metres, each vault was 12.5 metres wide. The whole roof sits on only 4 rows of columns with a maximum span of 35 metres. The overall thickness of the roof is only 100 millimetres, comprising a 75 mm thick brick and a 25 mm covering of sand and cement. When visiting the building what is most surprising is the 16.5 metre cantilever that extends over a later extension, which itself consists of a free-standing vault cantilevering 15 metres in either direction from a single row of columns, Fig 3. The double cantilever vaults supported on a single row of vaults occurs quite often in his work. They challenge our perceptions of security as they seem to balance precariously. The Bus Station at Salto consists of 7 balanced vaults cantilevering 11.5 metres from a single central row of columns, Fig. 4. These structures demonstrate Dieste's ability as an engineer to provide a minimal and efficient structure. The formwork systems he developed could be struck and repositioned quickly without being dismantled. Typically for a vault such as Salto one section of formwork would be constructed for one span or half the total length. Once the half vault had set it would be braced temporarily both horizontally and vertically and the formwork repositioned to construct the second half. The large spans between the support and the cantilevers were achieved through another of his innovations. He developed simple techniques for pre-stressing using looped tendons and specially designed jacks, showing his ambition for self-reliance. Conventional pre-stressing systems require expensive hydraulic jacks and anchorages. The concentration of forces at the anchorages needs extra reinforcement, carefully detailed to prevent bursting. Dieste's looped tendons, distribute the pre-stress across the width of the vault, reducing the concentration of anchor forces and maintaining the overall thinness of the vault. It is a solution that fits the structural needs for pre-stressing, is an appropriate application of technology and does not compromise the aesthetic expression. The most remarkable example of the typology is in structural terms not a vault at all: La Gaviota, the seagull, Figure 5, a canopy for a petrol station. It comprises two halves of a vault connected along a central valley. It uses the minimum possible structural support a single, central column. The canopy cantilevers over 8 metres either side of the column. After the petrol station was demolished the vault was transported as a single piece to a new location in a public park.

### **The Gaussian Vault**

The Gaussian vault is Dieste's masterwork of structure, Figure 6, the clearest demonstration of his desire to 'resist through form'. It extends the application of the catenary to much shallower and longer spans than the barrel vault. A brief analysis will show that even with much shallower vaults – span to rise up to 10 - the stresses due to self-weight are still low and within the allowable compressive stresses for brickwork. However shallow vaults are more likely to buckle. Buckling resistance can be increased by making the vault thicker or adding

stiffening ribs, both of which are practical solutions, allowing longer, shallower spans. However both are intellectually and practically flawed, resulting in greater thrusts and heavier support structures. The Gaussian vault relies on a doubly curved surface. The geometry is defined by a sequence of catenary curves spanning between two parallel lines that form the springing points of the vaults, figure 7. The catenaries vary gradually, rising and falling in height as they progress along the springing points generating the curved surface with maximum undulation at the mid-span and no undulation at the supports. A notable example is the Warehouse at Montevideo Docks. The original roof damaged in fire, was replaced with a vault spanning 45 metres. It consists of 14 discontinuous vaults, with a maximum rise of 6.5 metres at the centre. It is constructed using hollow clay blocks with a sand-cement topping to create an overall thickness of 130 millimetres, a span-to-thickness ratio of 345. Figure 8. Compared with a single curvature surface the Gaussian curvature uses approximately only 10% more material.

The analysis of such vaults is complex and Dieste developed analysis and design methods that he subsequently published, (Dieste, 1985). The effectiveness of his methods have been subsequently verified by non-linear FEM, (Pedreschi and Theodossopoulos 2007)

### **Churches and Architecture**

Dieste's most famous project is the Church of Jesus Christ the Worker in Atlantida, near Montevideo, figure 8 According to Dieste it was his 'school of architecture'. He was responsible for all aspects: design, structure and construction. The complexity of its form with undulating walls and roof that could be read as the product of a capricious and stubborn architect is actually based on a profound structural logic and concern for economy. The construction of the walls is much simpler in brick than concrete as formwork is not needed. The roof is a Gaussian vault. Lateral stability is provided by the connection between the vault and the roof. The cross-section of the church describes the bending moment diagram, figure 9. The precision and care during construction is evident internally at the intersection between the separate undulating surfaces of the wall and roof.

Towards the end of his career Dieste was involved in a number of projects in Spain with the construction of a series of churches for the newly formed Diocese of Alcala de Henares. The first three of these were based on original projects in Uruguay, including the Church of Jesus Christ the Worker. Most significant was the church of San Juan de Avila, based on an ambitious project that was never finished in Montevideo. The 11 metre high doubly curved walls are only 300 millimetres in thickness, figure 10.

Concluding remarks

There is so much depth and many layers to his work that it is difficult to decide what must be said and what can be left. Please look for yourself. His work should inspire all engineers to evaluate what they do and how they approach their own work.

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## Figures



Fig. 1 Eladio Dieste (Vincente del Amo)



Fig.2 Free standing barrel vault, Refrescos Del Norte (Vincente del Amo)





Figure 3 Agro-Industry Massaro, (R Pedreschi)



Figure 4 Bus Station at Salto, (Vincente del Amo)





Figure 5 La Gaviota Salto, (Vicente del Amo)



Figure 6 The Don Bosco Gymnasium, Montevideo, (R Pedreschi)

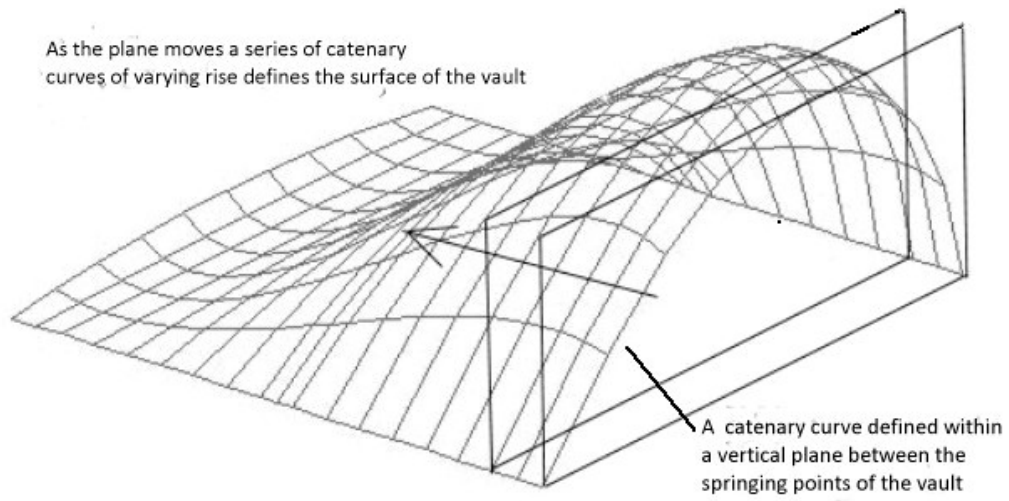


Figure 7 Development of Gaussian Vault surface, (R Pedreschi)



Figure 8 The Church of Jesus Christ the Worker, Atlantida, (R.Pedreschi)

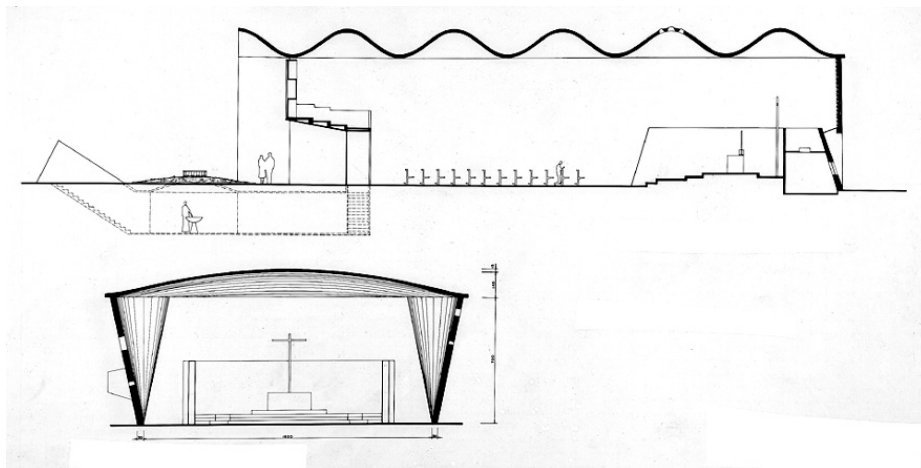


Figure 9 Sections through the Church of Jesus Christ the Worker, (Dieste Archive)



Figure 10, The Church of San Juan de Avila, Alacala de Henares, Spain, (R. Pedreschi)