Study of Rampant slab for complex geometric element of Arch Profile

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***Abstract*—Structural integrity in masonry construction has been a key focus of research for decades. Arches and vaults are fundamental elements in preserving this integrity, particularly in historical and monumental architecture. Since the 18th century, the evolution of domes and the integration of complex geometrical components such as masonry stairs and slabs have introduced significant structural challenges. Among these, the rampant arch plays a critical role in staircase stability, yet remains less standardized in architectural literature. This study investigates the structural behavior of rampant masonry arches, emphasizing the influence of arch profiles particularly segmental forms on load distribution and stress minimization. The analysis highlights the importance of profile geometry and masonry selection in optimizing compressive strength and ensuring performance under varying loads. These findings position rampant slabs as key elements in the advancement of sustainable and resilient architectural design.**

***Keywords*—Rampant, Geometry, Thrust line, Arch, Masonry.**

I. INTRODUCTION

Masonry construction has played a fundamental role in the architectural and structural development of civilizations throughout history [1-2]. Among the various structural systems developed, masonry arches and vaults have been widely recognized for their inherent ability to maintain stability through compression. Over the centuries, these structural forms have not only provided mechanical strength but have also significantly influenced architectural aesthetics, particularly monumental buildings and heritage structures [3-4]. The evolution of masonry construction techniques can be traced back to ancient civilizations, with particular advancements observed during the 18th century, when domes and vaulted systems became prominent features of monumental architecture. These structures posed considerable challenges in terms of design, particularly when incorporating complex geometric elements such as staircases, ramps, and masonry slabs [5-7]. Ensuring both aesthetic appeal and structural integrity in such constructions remains a significant challenge, especially in load-bearing systems. Among these structural forms, Rampant arches represent a particularly demanding architectural feature. A Rampant arch is characterized by its unequal springing points—one side of the arch rises higher than the other—making it especially suitable for structures with uneven load distributions, such as staircases or sloping passageways. While widely used in Gothic architecture and certain vaulted systems, the term Rampant arch has not been as extensively standardized or explored in modern structural analysis literature [8-10].

Given the challenges associated with the stability and load distribution in Rampant arches, particularly under non-uniform loading conditions, there is a need for systematic analysis supported by modern computational tools. This study addresses that need by employing Finite Element Analysis (FEA) using ANSYS software to evaluate the behavior of Rampant masonry arches under varying geometrical configurations and load conditions [11-15]. Instead, thrust line approaches use processes that compute the line of thrust by solving the equilibrium equations or a linear programming problem and determine the zone where the inner forces (i.e., the thrust line) can stand in order to determine the safety level [16-19] The greatest bearing capacity is shown by the catenary arch. As a result, engineered materials are used in arch bridge design to guarantee that the components have remarkable load-bearing capacity. The catenary arch has been used for this purpose in order to construct the porous structure [20]. Regarding this subject, it is important to note that certain writers have already created techniques for creating arches whose geometric axes match the thrust line [19-21].

The primary objective of this research is to investigate how variations in arch geometry influence load transmission, thrust line positioning, and overall structural behavior. Through this analysis, the study aims to contribute to both the academic understand-ing and practical applications of Rampant arch design in modern conservation and construction practices.

II. OBJECTIVE

The primary objective of this research is to investigate the influence of geometric variations on the structural stability and behavior of masonry arch structures. Arches, vaults, and domes have historically played a critical role in architectural design, offering both structural efficiency and aesthetic value. These forms are widely utilized for their ability to span large distances, distribute loads effectively, and minimize the need for intermediate support.

This study specifically focuses on the following aims:

1. To investigate the impact of varying arch profiles and slight geometric modifications on the stability of masonry arch structures.
2. To analyses the structural behavior of two distinct arch profiles subjected to different loading conditions using finite element analysis (FEA).
3. To evaluate the deviation of the thrust line from the D/6 criterion for each profile and assess its implications for structural integrity.
4. To emphasis the importance of accurate geometric design in ensuring the safety and reliability of masonry arch constructions.

By addressing these objectives, the research aims to contribute to improved understanding and optimization of masonry arch design in contemporary structural applications.

III. METHODOLOGY

ANSYS is leading engineering simulation software used across industries such as aerospace, automotive, and healthcare. It provides tools for structural analysis, CFD, and electromagnetic simulation, primarily employing finite element analysis (FEA) to predict product behavior under various conditions. ANSYS helps reduce development time and costs by enabling virtual prototyping, design optimization, and advanced visualization.

Finite Element Thrust Line Analysis (FETLA) combines the simplicity of classical thrust line analysis with the flexibility of finite element modeling, allowing efficient assessment of complex masonry geometries.

Modeling Approach

Rampant masonry arches were analyzed using finite element analysis (FEA) in ANSYS to study their structural behavior under non-uniform loading. The arch portion was modeled as load-bearing, while the remaining masonry was treated as dead load.

Material Properties

Mechanical properties were selected based on practical experience in masonry construction. Minor variations in these properties have minimal influence on thrust line location.

Table 1 Mechanical Properties (Assumed for Geometry)

Property	Value	Unit

Density	2000	Kg/m^3
Modulus of Elasticity	$1.65x10^9$	N/m^2
Poisson Ratio	0.15	
Gravity	9.81	m/s^2
Element type	Plane182	

The modulus of elasticity Em, assuming M1 mortar and a 3 MPa masonry unit (basic compressive stress factor = 0.05), is calculated as: $Em=550\times Fm=550\times 0.1\times 3MPa=1.65\times 10^{9}\ N/m^{2}$

IV. Experimental Analysis

The attached drawing represents a Rampant Masonry Arch constructed beneath a straight staircase. This is a practical example of using rampant arches to minimize excessive filling and optimize structural performance.

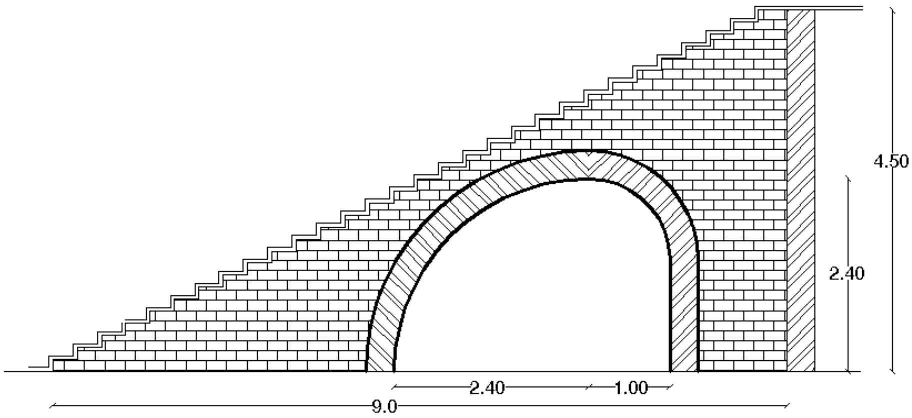


Figure 1 Typical Rampant Staircase Configuration

In modern staircase construction, excessive filling especially across large height differences leads to increased material usage, higher costs, aesthetic compromise, and potential settlement issues. To address these challenges, integrating rampant masonry arches offers a structurally efficient and architecturally refined solution. Rampant arches improve load distribution, reduce fill volume, and can function as waist slabs, enhancing overall performance. This study investigates the effectiveness of various rampant arch profiles in staircase systems using Finite Element Analysis (FEA), aiming to optimize both structural integrity and spatial design through strategic use of masonry.

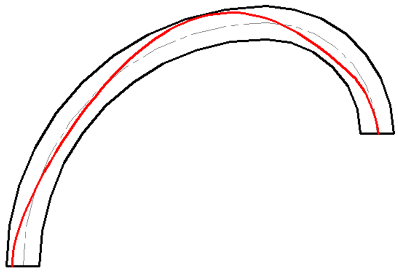
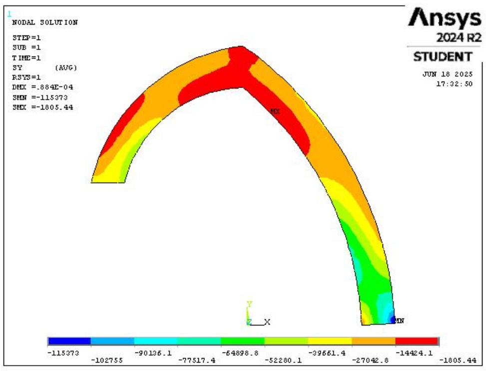
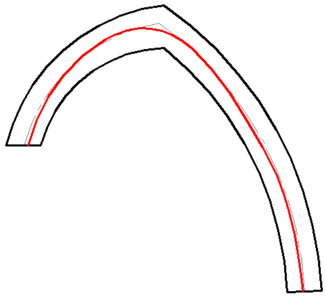
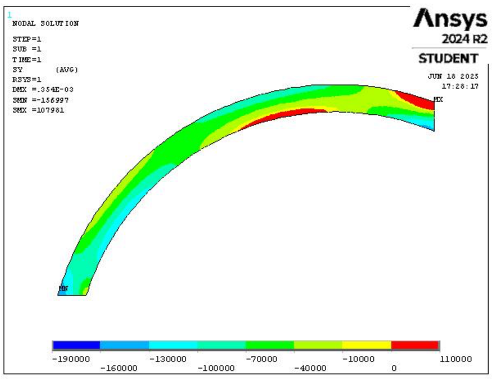
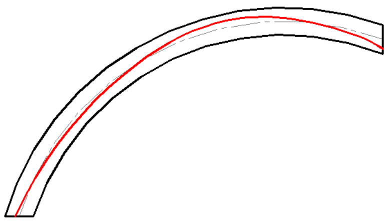
Performance Evaluation Criteria

The evaluation of each geometry was based on the following critical parameters:

1. **Stress Distribution:** Identification of tensile and compressive zones within the arch.
2. **Thrust Line Behavior:** Analysis of thrust line location and its eccentricity relative to the arch thickness.
3. **Eccentricity-to-Depth Ratio:** Comparison with the recommended limit (D/6 rule) for masonry structures to assess stability.
4. **Architectural Suitability:** Assessment of how each profile impacts usable space and architectural refinement beneath the staircase.

Performance Analysis

Following are the analysis of different geometries performed for the provided staircase.

Type of Geometry	Stress Diagram	Thrust line
Geometry 1: Segmental Rampant Arch		
Geometry 2: Pointed Rampant Arch		
Geometry 3: Catenary Rampant Arch		

V. Results Interpretation

Principal stress vector diagrams were used for thrust line visualization and tensile stress identification.

Cylindrical coordinate stress resolution further clarified stress distribution.

Thrust line plots followed the method of Varma and Ghosh [Varma & Ghosh, Int. J. Masonry Res. Innov., 2016].

If the thrust line remains within the geometry—preferably within the middle third—the arch is considered structurally safe, ensuring high stability [Heyman, Int. J. Solid Struct., 1966].

VI. Discussion

This study conducted a comprehensive investigation into the structural behavior of rampant masonry arches employed beneath staircases, with the objective of minimizing excessive filling while improving both structural performance and architectural efficiency. Utilizing Finite Element Analysis (FEA), multiple rampant arch profiles were assessed for their stress characteristics, thrust line behavior, and overall stability under staircase loading conditions.

VII. Conclusion

The comparative finite element analysis of rampant masonry arch configurations under staircase applications establishes the catenary rampant arch as the most structurally efficient and architecturally viable solution. While segmental and pointed configurations were limited by tensile stress concentrations and spatial inefficiencies, the catenary profile demonstrated superior load transfer characteristics, closely aligned thrust line geometry, and minimal tensile stress development. Eccentricities frequently exceeded the permissible D/6 limit. Therefore, segmental arch is structurally unsuitable due to instability and the presence of tension.

Further geometric refinement and design optimization could lead to the complete elimination of tensile zones. This study highlights the catenary rampant arch as a technical sound compared to segmental arch. In other words, segmental arch does not have the right approach to staircase zone.

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