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Determination of the causative mechanism of structural distress in the presidential palace of India

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ABSTRACT

The presidential palace of India was constructed between the years 1912 to 1929 CE in a novel architectural style resulting from an amalgamation of Colonial and traditional Indian styles. During a visual inspection of this double-domed structure, meridional cracks were spotted in two out of the four niches in the drum of the lower dome. The observed distress raised two important issues that needed to be resolved- the cause of the cracks and their impact on the structural response. The uncertainty in the actual geometry of the building and the variety of materials used in its construction, the complex layout, lack of prior knowledge of reinforcement details and the undocumented changes made to the structure prompted the adoption of a multi-disciplinary scientific investigation to evaluate the structure. The methodical approach encompassed a literature review of dome failures in the past, historical and geometrical surveys, foundation inspection and the use of relevant non-destructive and minor destructive tests in the evaluation of the superstructure. The information gained from the aforementioned investigation was useful in the development of a 3D finite element model of the structure. The findings of the investigation revealed that owing to its geometry, tensile stresses develop in the unreinforced brick masonry drum. The reduction in the thickness of the drum at the locations of the niches results in an inherent weakness in the structure. The opening for the stairwell in the north-eastern corner of the building, at the level of the drum, further reduces the tensile resistance of the abutment system of the dome and gives rise to the observed crack pattern

1. Introduction

The Rashtrapati Bhavan has been the official home of the President of the Indian Republic since the year 1950, prior to which, it functioned as the Viceroy's house. Edwin Lutyens was appointed as the architect of the Viceroy's house in 1911, when the British moved the administrative capital of India from Kolkata to Delhi. In the early stages of the design, Lutyens conceived the structure in a style he was Au fait with- a classical European building with a high Renaissance dome and Palladian windows. However, he was made to alter the design so as to incorporate traditional Indian architectural elements as well, ergo the high Renaissance dome atop the building was replaced with a flatter Indian dome and elements like the chattri (roof pavilion), chajja (sunshade) and jaali (stone latticework) were added to the structure [1]. A cream-coloured sandstone railing encircles the upper dome lending it a strong resemblance to the stupa at Sanchi. The forecourt of the Rashtrapati Bhavan is seen in Fig. 1. Some of the typical Indian architectural elements used in the structure are shown in Fig. 2. Thus, with the construction of the Viceroy's House, Lutyens invented a new order,

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Fig. 1. The forecourt of the Rashtrapati Bhavan.

Fig. 2. Traditional Indian architectural elements in the structure- chattri, chajja, jaali and the Sanchi rail (from left to right).

which was an amalgamation of the Indo-Saracenic and classical European styles.

With a floor area of roughly 19,000 m^2, the Rashtrapati Bhavan has three storeys- a lower basement, an upper basement and the main floor, which houses the Durbar Hall, a ceremonial auditorium. The Durbar Hall, known as the Throne Room during the British times, occupies a central position in the building (see Fig. 3) and is the main venue for all the official functions in the Rashtrapati Bhavan. A reinforced concrete (RC) dome surmounts the Durbar Hall, while the upper dome, composed of masonry with copper cladding, crowns the exterior of the building. Lutyens drew inspiration from the Pantheon in Rome in the construction of the lower dome [1]. The use of cream and red sandstone cladding throughout the building is reminiscent of the structures built by previous dynasties that ruled Delhi. Marble is used as facing material in some of the interior parts of the structure. The building is mostly comprised of load-bearing brick masonry walls, with floor slabs made of Reinforced Cement Concrete (R.C.C.) and a few elements, such as the sunshades, of reinforced lime concrete. The colonial buildings constructed in the first half of the twentieth century mark the introduction of reinforced concrete in engineering practice in India [2]. Prior to this, the load bearing parts of structures were only composed of masonry. The Rashtrapati Bhavan is a pioneering structure in many ways and is thus a very important part of the architectural heritage of India. Given its significance in the socio-political context of the country, the preservation of this monument is essential.

As part of an extensive conservation plan for the buildings in the Rashtrapati Bhavan complex, a visual inspection of the main structure was carried out. During this assessment, two locations of structural distress in the Durbar Hall were identified. The RC dome, which forms the ceiling of the Durbar Hall, rests on a brick masonry drum. In each of its diagonal corners, the drum has a niche (semi-circular recess) carved into it. The niches are clad with marble, while the rest of the drum is plastered with lime. The north-eastern niche shows a meridional crack of significant dimension, while the diametrically opposite niche has two smaller cracks, as seen in Fig. 4. From the ground level, the other two niches do not appear to have developed any cracks. According to the archive drawings of the Rashtrapati Bhavan, the building is symmetric about the east-west axis. Therefore, the asymmetry in the crack distribution engenders ambiguity in the evaluation of its cause and effect.

2. Behaviour of domes and their supporting systems

Load transfer from a dome to its supporting structure takes place through the development of longitudinal meridional forces, which are compressive in nature. The magnitude of these forces increases from the crown towards the base. In order to prevent buckling, hoop stresses arise along the circumferential direction. In hemispherical domes, these stresses are compressive in the upper part of the dome and tensile below a co-latitude of 51.82° [4]. Given the specific weight of the material of the dome (γ), the stresses acting on a hemispherical dome are represented in Fig. 5. The appearance of meridional cracks in masonry domes is common and