# Structural Analysis of Bridges and Viaducts Using the IoT Concept. An Approach on Dom Pedro Highway (Campinas - Brazil)

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**Abstract.** Bridges are constructions whose aim is to connect two points separated by natural or artificial hindrances. They have been used since ancient times but, in the last decades, due to the increase of vehicles' quantity and flow, cities needed to make use of these structures to avoid the crash of their road network, connecting the strategic points with viaducts. As the viaducts are built above ground, they are much more susceptible to the aggressiveness of external agents, e.g., the wind, the rain, and the vehicles' traffic itself, once there is not a solid base underneath them. For more reinforced the viaduct construction is, it is unavoidable that, with time, damages appear in the structure and, for that reason, the screening and preventive maintenance of the failures are indispensable from the points of view of the users' safety and the economic impact that a structural collapse may bring. Currently, this analysis is made manually by the engineers of the responsible agencies (public or private), and this article will show how this procedure is performed with examples of the city of Campinas (Brazil). In light of the evolution of the IoT concept in a wide variety of knowledge fields, the authors consider that civil engineering can also take advantage of this technology to automate the data collection and decision-making in the prevention of structural failures, and a project is proposed to that end.

**Keywords:** Structural analysis · IoT · Road characteristics · Civil engineering · Urban mobility

## 1 Introduction

A bridge is a construction that connects one side to the other, giving the flexibility to move between non-accessible points, such as valleys, rivers, and others with


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natural or artificial aspects. They are used for the passage of people, pipelines, water pipes, or even small or large automobiles [1–3].

According to Silva, these works, which are called Specific Constructions, have great significance for the growth of cities [4]. The viaducts and bridges represent a large part of the works that belong to the road systems. This construction has the objective of overcoming blockages that can be the rivers, valleys, and avenues [1–3].

With the population and the growth of small and large automobiles, causing major traffic jams on both roads and railways, the idea of building a bridge or viaduct was to interrupt the flow in the area [5–7]. The most common construction of a bridge (viaduct) is made of reinforced concrete with large steel reinforcement to be more resistant to the passage of cars or trucks. Nowadays, there are several types of bridges, such as metal bridges, concrete bridges (reinforced or prestressed), mixed bridges (those that can contain steel/concrete or steel/wood), stone bridges, and wooden bridges [5–9].

The bridges that are built over the sea or rivers are made with pipes (metal tubes) with a diameter of up to 3 m that are stuck in the sea or river bottom. The water inside them is removed by pumping with compressed air system, keeping the inner part always dry so that the sea or river floor can be excavated to settle the pipe. As the excavation progresses, the pipe penetrates the ground, and after, it is filled with concrete and a block, which will serve as the base of the pillar, is built at its top [5–9].

The caissons are reinforced concrete or steel structures that are dug out and the abutments are made in the same way as the tubular; these bridges are usually built to a depth of 50 m. The metal structures can be reused in the abutment, but in some cases when the construction is completed it can be removed [5–9].

These constructions are subject to all kinds of external actions that come from the force of the winds, the mobile loads of cars, temperature variations, and the action of water. In addition, these works are built-in environments that are subject to numerous categories of aggressiveness class, according to the standards presented by ABNT NBR 6118:2014 [5–9].

Nowadays, bridges or viaducts can undergo several pathologies based on their foundations so that their useful life is not undermined by erosion or even earth movement. With consequences that can generate safety and damage to the road system, daily maintenance would already be one of the measures [5–9].

In this work, a case and field study will be presented, specifically in the region of Campinas - Brazil, to demonstrate flaws in the analyzed structures, and to demonstrate the danger of these structures for numerous aspects, and finally, to demonstrate the importance of implementing the technology (e.g., IoT) as a way to carry out a constant analysis, and avoid possible problems and incidents for the analyzed structures and constructions, in addition to this proposed system having an environmental, social, and financial impact for everyone involved [7–10].

## 2 Theoretical Background

A bridge is a construction that allows one side to be connected to the other even at non-accessible levels that are separated by natural or artificial obstacles. They are built for people, small or large automobiles, trains, or even pipelines to allow faster and safer access [11–15].

Bridges are built over watercourse obstacles or any other liquid surface, such as the sea or rivers. The viaduct, on the other hand, is a construction that has the same purpose as a bridge and is built over obstacles, such as a road or highway. There are several types of bridges, such as [11–15]:

– Wooden bridge: in ancient times, when man did not even know what a bridge was, tree trunks were used to cross over a river or valley. But it became recognized as a wooden bridge in 1758 when a bridge was created over the Rhine River with a span of 118 m.
– Stone bridge: the Romans, even before Christ, built stone bridges in the shape of a semicircular arch with a span of up to 30 m. During the Middle Age, some bridges reached a span of 50 m.
– Metallic bridges: they appeared at the end of the 18th century in cast iron, and it was only in the middle of the following century, with the railroads with heavy loads, that steel was firstly used in the construction of bridges. In 1850, the first truss bridge was built, with a span of 124 m.
– Reinforced concrete bridge: in the early 20th century, the first concrete bridge appeared. Starting in 1912, the construction of beam and frame bridges in reinforced concrete with up to 30 m of span came into being.
– Prestressed concrete bridge: from 1938, the first prestressed concrete bridges came to light, but there was a great need to build prestressed bridges after the Second World War. It was necessary to build bridges quickly because, during the war, several bridges were destroyed.

Nowadays, bridges are classified by their use, such as railway bridges (for train traffic), road bridges (for car traffic, in urban areas this bridge is characterized as a viaduct), pedestrian bridges (better known as footbridges, for the safe traffic of people), pipeline bridges (for the traffic of chemicals or even water).

### 2.1 Building a Bridge

Pillars are metallic tubes that are stuck approximately 3 m deep in the seabed. The water that remains inside is removed using a pump. Inside, a compressed air system is implanted so that it can excavate for the placement of the pipe. As the excavations go on, the pipe enters the ground and, when it has already penetrated the soil, the pillar is filled with concrete. At this time, divers must monitor the process to verify the grout rising inside the form to avoid leaks; more care must be taken for the removal of the hopper [11–15].

The pipe inside the form should rise gradually as the level of concrete is being poured. The concrete level should never go over the top, otherwise, the concrete would be contaminated with seawater. A block is built on top of the filled pillar, which is also made of concrete and is the base of the supporting pillar [11–15].

Caissons are made of steel structures or even reinforced concrete, just like the tubular. Usually, the bridges are built in places closer to the continents where the depth varies around 50 m.

### 2.2 IoT - Internet of Things

The IoT is going from childhood to maturity and establishing itself as part of the Internet of the future [16]. The Internet is a global system of interconnected computer networks that use the same set of protocols (TCP/IP) to serve billions of users worldwide. It is a network made up of millions of private, public, academic, business, and government networks connected through a broad range of technologies of electronic, wireless, and optical networks [17].

Nowadays, there are more than 100 countries linked with the data, news, and opinions exchange through the Internet. According to the Internet World Statistics, on December 31st, 2011, there were about 2,267,233,742 users on the Internet, which was equivalent to 32.7% of the world population [10].

IoT consists of installing sensors (RFID, IR, GPS, scanners, and others) for everything and connect them to the Internet using specific protocols for information exchange, aiming to develop applications for smart recognition, location, tracking, monitoring, and management. The new applications of IoT are making possible the initiatives of smart cities around the world. They offer the capability to remotely monitor, manage, and control devices and create new insights and information from massive data flows in real-time [18].

## 3 Scientific Research

### 3.1 Investigative Methodology

This topic aims to show that researchers and the academic community have been giving significant contribution to avoid wastes concerning the innovation of civil engineering. At the base of these investments, there is the implementation of technologies, especially IoT, to improve the building sector, concerning the constructions and their different characteristics, with the view to bringing innovation and advantages in the aspects of time, costs, sustainability, and safety.

This theme has been discussed for some years. In the bibliographic review of this work, the authors verified articles from 2013 and observed that over the years the topic of innovation in civil engineering has been growing in publication numbers, impact factor, and citation numbers [19–30].

In the articles analyzed, there are many metrics, norms, sensors, and applicabilities in different kinds of buildings. However, all of them focus on the modernization of the building sector and the practical application of the proposed solutions, which use IoT technologies and bring numerous benefits. In this context, the concept of “Smart Buildings” arose.

### 3.2 Proposed Methodology

The methodology proposed by the workgroup consists of an application created with the tool Dojot, which is an IoT platform directed to the development of smart cities [31].

The platform Dojot is an open-source initiative designed in Brazil that aims to facilitate the development of solutions in an IoT ecosystem concerning Brazilian needs [31].

Dojot is a platform based on state-of-the-art technologies and adopts an architecture of microservices, which allows a functional, customized, and scalable deployment as well as easy integration with other systems based on services. Figure 1 shows an overview of the platform [31].

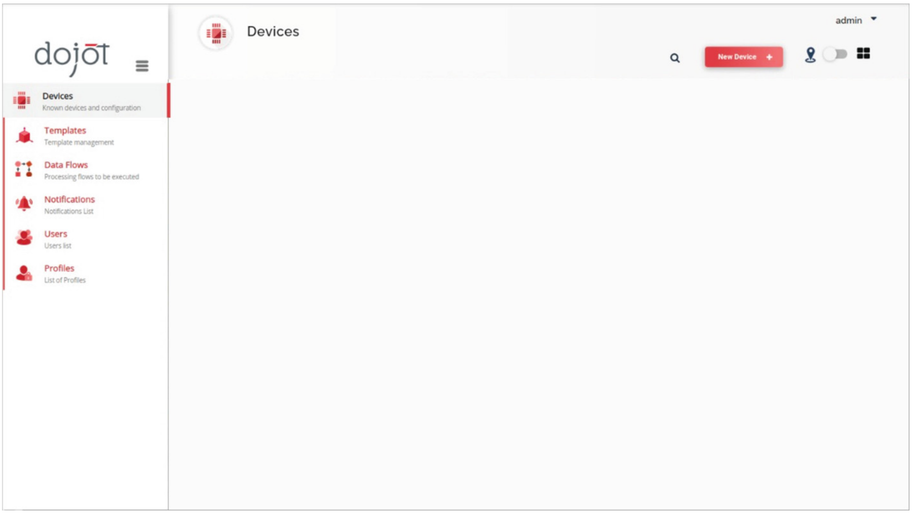


**Fig. 1.** Dojot platform

## 4 Field Research

A case study was conducted in Campinas (Brazil) about the Dom Pedro and José Magalhães Teixeira highways, where photos and information of the Dr. Roberto Rocha Brito and Manoel Aveiro viaducts were obtained. The field research had the objective of verifying the viaducts structures, the size and dimension of the pillars, beams, and slabs, the width of the components, lanes, shoulders, and what kind of vehicle movement these viaducts receive every minute, and whether they are cleaned or not. The main reason for this is the fact that both viaducts are very important for the city of Campinas and the region, and the authorities (e.g., the roadway concessionary and the public agencies of Campinas) must provide investment for the maintenance and safety of the viaduct.

### 4.1 Manoel Aveiro Viaduct

The strategic master plan is an appropriate concept, which aims to present new proposals for urbanization in a territory, whether municipal, state, or federal, integrating coherently the territory with the installed population, with the principle of achieving an egalitarian city with opportunities for all.

The Manoel Aveiro viaduct is located on Rodovia José Magalhães Teixeira, at km 3.45 in the interior of São Paulo, in the city of Campinas. This viaduct is in the direction from Campinas to São Paulo, before the access to Anhanguera and Bandeirantes highways. In the opposite direction, it is towards Souzas district and with access to Dom Pedro Highway. It was one of the subjects for reform and expansion of the master plan, carried out in Campinas in the year 2006.

Figure 2 shows two central pillars supporting the viaduct, which are damaged and require maintenance. Figures 3 and 4 show that the rainwater is coming out through the viaduct curtain, and if this structure is not maintained, it can be damaged in the long term.

Figure 5 shows a green area on the highway in both directions, which is protected with guardrails. The street is damaged and has no lighting at night. Figure 6 shows the central pillar, the spar and transversal spar, and the shoulder on both sides.

Figure 7 shows the stringers and several transversals with a reinforced concrete structure and the guardrail. This viaduct has a small footbridge for pedestrians and cyclists.

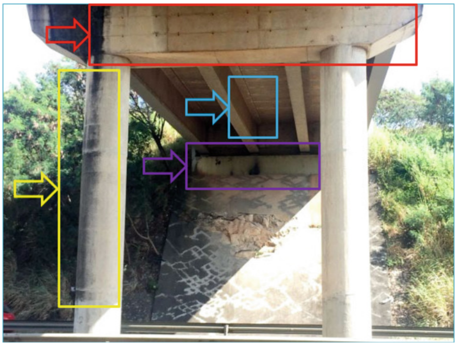

**Fig. 2.** Manoel Aveiro viaduct

**Fig. 3.** Manoel Aveiro viaduct

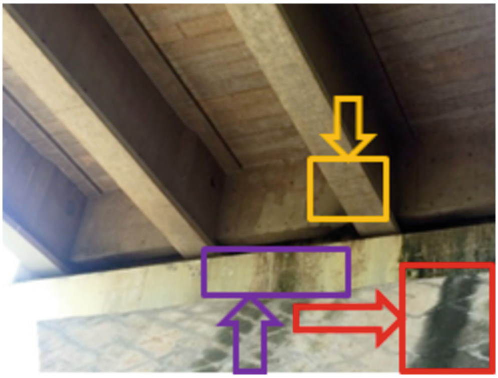

**Fig. 4.** Manoel Aveiro viaduct

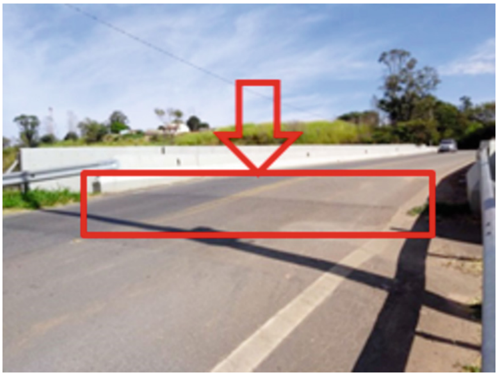

**Fig. 5.** Manoel Aveiro viaduct (Color figure online)

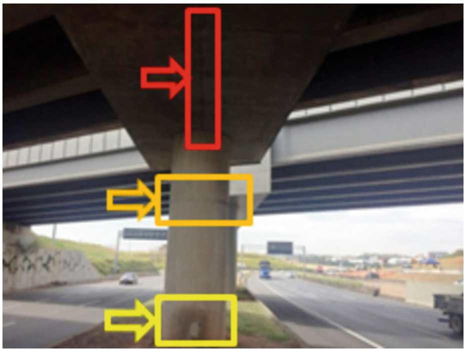

**Fig. 6.** Manoel Aveiro viaduct

**Fig. 7.** Manoel Aveiro viaduct

### 4.2 Dr. Roberto Rocha Brito Viaduct

The Dr. Roberto Rocha Brito viaduct is located at km 136 of Dom Pedro highway, in the interior of São Paulo, in the city of Campinas. Figure 8 intends to show the field images, such as; pillar, support beam, lane strips, shoulder, water drainage area, cracks, and cleaning and maintenance that the bridge must receive, through preventive works.

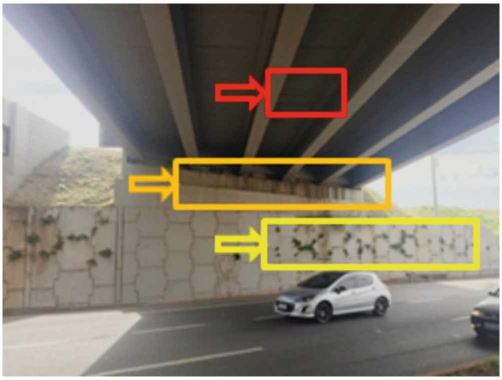

**Fig. 8.** Dr. Roberto Rocha Brito viaduct

## 5 Final Consideration

The current work presented a case study in the city of Campinas (Brazil), specifically in two viaducts. The workgroup analyzed critically the fissures and cracks in the viaducts' structures through photographs that were took in loco and demonstrated some climatic, environmental, and wear damages present in the structures.

As shown in the Figs. 9 and 10, there is a latest trend in the acquisition of technology, mainly IoT, by Civil Construction, to facilitate and ensure outdated and rudimentary methods and processes, avoiding any problems of pathological scope in the structures like those presented and evidenced above, in Figs. 2, 3, 4, 5, 6, 7 and 8.

**Fig. 9.** The Internet of Things in construction

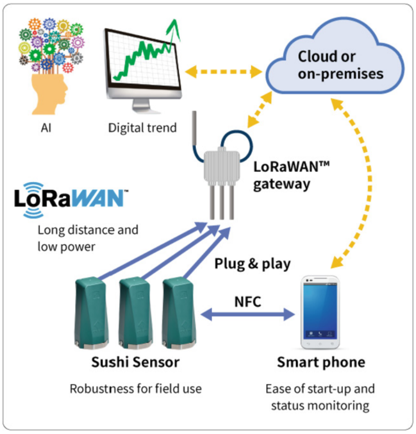


**Fig. 10.** The Internet of Things in construction

This work focused on learning and improving knowledge about bridges and viaducts, providing information of great importance for installing a bridge or viaduct correctly, always following basic premises. However, the main objective of this work was a case study, specifically in the region of Campinas, Brazil, which evidenced numerous problems in the structures, presented in the previous figures, and brings uncertainties and high costs for their maintenance. Having demonstrated this problem, the main focus of this work is to emphasize the importance of the applicability of the IoT technology integrated with platforms like Dojot in real-time data collection in buildings. Aiming to analyze in real time possible impacts and instabilities on the part of the system, and with that, carry out preventive actions.

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