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Structural Inspection by RPAS (Drones): Quality Work with Preventive Guarantee

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ABSTRACT

The use of Remotely Piloted Aircraft System (RPAS), better known as drones, has spread with multiple and very diverse applications on last years. It includes, among other matters, the civil engineering structures inspections. From an inspection of a viaduct this article was born precisely. The inspection was conducted by the author experimentally, in order to demonstrate that the little aircraft can serve as a quality tool to make this work that is being carried out by qualified personnel and expensive auxiliary means currently. At the end, the author try to demonstrate that we can obtain identical, or even better, quality results, reducing the health and safety risks for the workers who do that work, with time and costs significant savings.

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Introduction

On November 6, 2021, the author of this article participated in a viaduct detailed main inspection with other professionals, with the exclusively experimental purpose of verifying the applicability of drones to carry out this type of inspection.

In fact, this intervention was based on the conviction, on the part of the participating technicians, that the inspection of structures is essential, because it allows obtaining the necessary data to know the functional, resistant and aesthetic state of a structure at any given time. At the same time, using a drone, the work is much cheaper and faster and safer for the workers as well.

An inspection is essentially based on checking, characterizing and monitoring the structure as a whole and each of the different elements that make it up. Depending on the type and scope of the inspection carried out, this inspection may be accompanied by tests that complement the diagnosis made through visual inspection.

As the inspection was carried out in Spain, the criteria spanish ministry has been considered [1,2]. Obviously, there are many other classification criteria followed by many other institutions and organizations that could be applied for this purpose [3-5]. So, different types of inspection included in the various guides developed by the Spanish Ministry of Public Works (Ministerio de Fomento) to inspect the road network step structure are the following [1]:

1. Routine inspection. It is a basic inspection performed by unqualified personnel. These personnel are usually the structure maintaining workers. According to the Guide, these inspections are carried out on every structures with a span of 1.00 m, or more of course, to properly monitor their condition and thus detect apparent failures as soon as possible. If these faults are not detected on time, they could lead to significant conservation costs or repair costs, if they are not corrected on time.
2. Main inspection. This kind of inspection is deeper than routine inspection; however, it is essentially visual still. It must include every structure visible elements examination. It implies the possible need to use means auxiliary of access. Therefore, depending on its complexity (Figure 1), the main inspection is subdivided in two possible categories [2]:
   a. General main inspection. This inspection consists in a detailed visual observation of every visible elements, without the need to use extraordinary auxiliary means of access. In other words, means more complex and more expensive than, for example, a manual climbing ladder.
   b. Detailed main inspection. In this inspection, unlike the previous one, it is essential to use extraordinary means of access that allow the inspection of all visible parts. In this sense, we have to differentiate between accessible and visible: an element can be visible and not accessible or easily accessible.
3. Special inspection. This kind of inspection, unlike the rest, does not have to be done systematically. This kind of inspection generally arises as a result of damage detected in a main inspection or, exceptionally, as a result of a singular situation. In these inspections, in addition to the visual examination we have previously mentioned, we will need complementary tests and measurements, with special techniques and equipment. This level of recognition requires a plan prior for the inspection, detailing and assessing the

aspects will be studied, the techniques and the means to be used as well.

It should be noted that the previous classification criterion has been extended to more areas than road structures [6-8]. This is the reason why it has been decided to present it here as a starting point.

Figure 1: Operations within A Special Inspection Carried Out in A Mixed Structure (Concrete and steel) using A Personnel Lifting Platform (author's Photograph)

On the other hand, the concept of aircraft without an onboard pilot, Unmanned Aerial vehicle (UAV) or even Remotely Piloted Aircraft System (RPAS) as well emerged a few years ago. All of them are synonyms; all of them are referred to drones; all of them refer to aircraft that can be controlled by the pilot remotely or that can be programmed, being completely autonomous.

The incorporation of some accessories to these aircraft, such as recording cameras or high-resolution image capture, and the development of increasingly precise and affordable microtechnology opened the door to the possibility of incorporating drones to carry out this inspections for some years [9]. In recent times, many advances have been made in civil engineering and this has led to the incorporation of drones to the inspections framed in the previous classification.

Thus, in order to carry out the inspection, a drone was used. Therefore, as the inspection was exclusively visual and a drone was used as an auxiliary mean (if we had not used the drone, we would have had to use extraordinary means of access to be able to analyze certain elements of the structure.), according to the previous classification, the inspection that we are going to present here was a detailed main inspection.

Materials and Methods

As we said in the introduction, on November 6, 2021, the author participated, together with other technicians, in a main inspection. The purpose of this inspection was exclusively experimental: we tried to verify the applicability of drones to carry out this type of inspection.

The viaduct inspected was the viaduct called La Jarosa, located near from Madrid. Specifically, the structure is located at the kilometer point (K.P.) of the highway AP – 6, very near to a aountain range (Sierra de Guadarrama) and very close to a dam as well (Figure 2). The bridge crosses a minor road and a small stream (Fuente Corneja).

In order to carry out the work, no type of execution plan or as-built plan of the executed structure was available. Nor was there any kind of prior damage assessment report. All information we were able to collect was obtained from external sources and public sources. In fact, it is not a big problem: the need to inspect an old structure with no documentation preserved can be very common in practice.

Figure 2: Aerial Photograph of La Jarosa Viaduct (Photograph from the Spanish National Geographic Institute)

The AP–6, the highway superjacent to the viaduct, has three roadways parallels, corresponding to Madrid direction (left lane), to the reversible direction (central lane) and to La Coruña direction (right lane), respectively. Each of these roadways has its own viaduct independent. As a consequence, there are three structures subject to inspection, and not just one.

The two oldest viaducts, the original ones, were built in 1963 and 1972 respectively (Figure 3). Later and to satisfy the growing demand for traffic, a third roadways was built. It is the roadway toward Madrid currently. So, the old left roadway has been left in the middle now, and it is the roadway reversible. Traffic direction is reversed on it, depending on the specific circulation needs. It forces to discriminate the old structures from the new one.

Viaduct on the right (viaduct that supports the right roadway, direction La Coruña) has nine isostatic spans with a span of 36.50 m (Figure 4). The height piers is between 7.40 m, for the lowest pier, and 27.60 m, for the highest pier.

Figure 3: Aerial photograph of the La Jarosa Viaduct image taken at the second structure conclusion (photography by Juan José Jover) [10].

In essence, we have a deck over concrete beams precast and prestressed, supported by abutments and hammer-type piers (Figure 4).

Every structure shaft has rectangular section. All of them have two interior rectangular lightenings with a variable dimension in the transverse direction. They have a landing on their head, forming a T with the shaft.

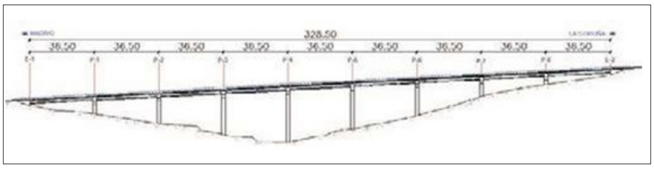

Figure 4: Viaduct Longitudinal Elevation, La Coruña Direction, Right Lane [11].

All the piers rest on isolated shallow foundations. The abutment are conventional over shallow foundation as well.

The cross section of the original deck had six prestressed concrete double T beams. These beams were 2.00 m deep, equally spaced 1.91 m and connected by the upper slab (0.20 m deep) and by transverse reinforced concrete braces located every 7.00 m. (Figure 5).

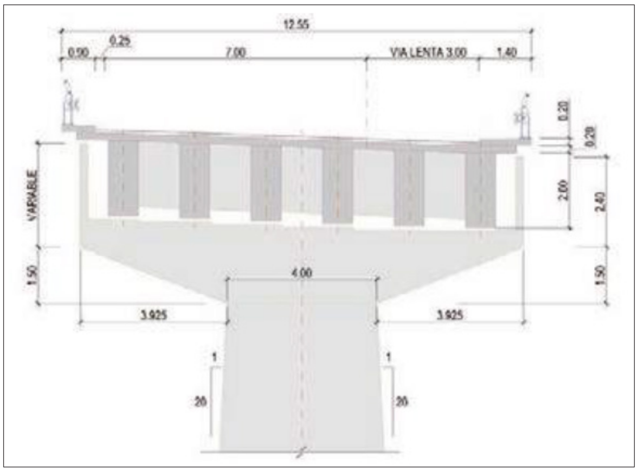

Figure 5: Viaduct Original Structure Cross Section, on the Top of the Piers and the Deck [11].

We know that various repair and reinforcement actions have had to be carried out on the structure. Without going any further, two years after the construction of the last viaduct (the youngest), movements were detected in some neoprene supports of piers 2 and 3. This forced a singular action. A mistake during assembly seems have been the cause of this anomaly: not all the supports presented similar displacements (one of them, in particular, received the beam in 30% of its surface).

On the other hand, the need to widen the viaduct towards La Coruña required to reinforce it. For this reason, some lintels were built that supported the previously existing. When these works were undertaken, this viaduct had two substantial limitations: the total width and the shoulders of the roadway did not meet the layout conditions and there was corrosion damage to the structure of the steel reinforcement.

A multitude of complementary actions have been carried out on the structure as well. For example, footbridges 15.00 meters long were installed. These footbridges allow the passage of maintenance personnel today, under the Viaduct roadway. These are prefabricated elements (manufactured in the workshop) from a piece of structural tube and tramex metal platform, with a hot-dip galvanized finish.

Figure 6: Metal Walkways installation for the Viaduct Maintenance [12].

Figure 7: Metal Walkways installation for the Viaduct Maintenance [12].

Results and Observations

There have already been incursions and studies in various fields of application of the use of drones in the field of civil engineering, especially highlighting the use of this equipment for carrying out photogrammetric flights that allow subsequent modeling and plans (cartographic applications), as well as questions hydrogeological or even issues related to the control of execution of civil works to cite just a few examples [13-17].

There are many and very diverse types of drones currently available so it is important to know in each case the most suitable type of aircraft for each situation, and particularly for the action analyzed here. Among all the classification criteria, the most interesting for this purpose is the one that attends to the form of support of the equipment in the air. In this way, a distinction is made between fixed-wing drones and rotary-wing drones [13,19,20]. There is no doubt that the fixed-wing drone has great advantages that make it suitable for many applications, but its inability to perform a vertical takeoff and maintain a stable position in the air does not make it suitable for the inspection of an old construction, unless that it is intended to take images of large surfaces, which is very rare. For this reason, the type of drone used for the works contemplated here is usually a rotary-wing drone, and more specifically a multirotor (Figure 8): they are drones with multiple propellers (always pairs) that take off vertically and have, in addition, the ability to turn on themselves, which makes them ideal for performing vertical work and maintaining a certain fixed position suspended in the air, in order to allow an accurate analysis to be carried out. Specifically, for this inspection, a Parrot brand quadrotor drone, model Anafi, was used.

Figure 8: Anafi Drone Flying Over Under the Beams that Support the Deck in the First Span (the Nearest to Madrid) to Recognize the Constituent Elements of the Viaduct (author's Photograph)

Damage due to corrosion has been observed in several of the elements of the structures (Figure. 9, Figure 10, Figure 11 and Figure 12). As we have already pointed out in section 2 of this article, the condition due to corrosion has already motivated previous actions. The location of the structure in a mountain area, where winter frosts are frequent and severe, makes it necessary to keep in mind the action of ice-thaw, as well as the crystallization of salts. This concentration of moisture, and the alternation of moisture - dryness, causes corrosion products to appear as a result of the reaction of oxygen and certain metals, mainly steel, in the presence of water or moisture [21].

We were also able to see salt stains, especially chloride stains, probably due to the winter dumping of salt on the road surface to combat ice and snow. Although the extended dosage is unknown, it is known that the extended salt is rock sodium chloride (not sea salt). When de-icing salts are poured on or under roads, chloride corrosion phenomena are very frequent, resulting in the formation of reinforcement corrosion products, as a consequence of localized acidification at the contact points of chloride ions (in a certain concentration), which gives rise to a localized oxidation reaction, in the presence of water [22].

Figure 9: Signs of corrosion in concrete and metallic elements. Note also the poor support of the staff, as two of the four bolts at the rear cantiléver (photograph taken with the Anafi Parrot drone).

Chloride contamination of concrete is one of the main causes of corrosion of reinforcing steel reinforcement. For this reason, modern technical codes and standards limit concrete content of chlorides that the different components that make up the concrete can contribute to fresh concrete, between 0.2 and 0.4% of chlorine ions by weight of cement (binder, in general), in reinforced concrete structures, and half (0.1 to 0.2%) in the case of prestressed concrete structures. These limitations are relatively recent. In this case, two of the three structures inspected are several years old. For this reason, it is really normal to find, in a structure of this age, chloride contents higher than those previous indicated. This is due to the incorporation of inappropriate water (we are very close to the mountain) or aggregates with a high content of salts. In addition, in the middle of the 20th century, calcium chloride was used as a setting accelerator [23-26].

As already mentioned, this structure is very close to a mountain range. The external contribution of chloride to the structure is also an important factor, especially when it is found in an environment of very low temperatures, and de-icing salt is also provided.

In an alkaline environment, a localized protective oxide coating forms on the surface of steel reinforcement. Chlorides can break down that protective shell. With that break, localized corrosion begins [27]. When the zones of this protective film break, they act as anodes (active zones), with respect to the still protected zones (or passive zones) in which the cathodic reaction of oxygen reduction will take place [28].

Figure 10: General View of a Concrete Brace, Arranged in the Web of a Precast Beam (Photograph Taken with the Anafi Parrot Drone).

Figure 11: Detail of the Element in Figure 10, Where a Chipping and the Consequent Corrosion of the Exposed armor Can be Seen (Photograph Taken with the Anafi Parrot Drone).

Figure 12: General View of the Shaft of One of the Piers, Where Corrosion Phenomena can be Seen that Affect different Constituent Materials of the Structure (Photograph Taken with the Anafi Parrot Drone).

Figure 13: Detail of the Area Photographed in Figure 12, Where the Corrosive Phenomena Can be Observed in Greater Detail (Photograph Taken with the Anafi Parrot Drone)

The remaining salts are of calcium origin, coming from the calcium oxide dissolution or the calcium hydroxide dissolution by rainwater [29]. The dissolution of these two compounds produces calcium bicarbonate. In a concrete element, under the action of the exterior elements, this compound precipitates as calcium carbonate [30].

However, the most of the characteristics of materials used and the environmental characteristics justify the presence of various corrosion phenomena [22,23]. It is true that it does not seem that any of them could be a concern, at least from the point of view of safety and structural stability, but they do have to be monitored periodically, since some elements or materials may be compromised due to durability.

In various concrete elements, part of the corrosive phenomena may be related to the scarce coating of the steel reinforcement, as has been recorded with the drone. The most significant elements in which this defect has been observed have been the lower faces of the prestressed beams in which the reinforcement frames have been perfectly visible (Figure 14). Despite the fact of the spectacular images, the structural importance of this damage is, in principle, nil. However, a regular check is very convenient [31].

Figure 14: Semi-Exposed Steel Reinforcement in Prefabricated Support Beam, as a Consequence of a Scarce Covering, Showing the Reinforcement Frames (Photograph Taken with the Anafi Parrot Drone).

The poles of the luminaries are also part of the structure. Their safety and stability is very important to avoid accidents. Upon inspection of the staves, we discovered that they were not properly anchored to the bridge deck [32] [33]. Not all the fixing screws of the base plate of the lamp support were fixed to the corresponding element (Figure 9).

According what we are talking about here, every structure auxiliary element is important for its effect over structural stability. Every structure auxiliary element must be subject to inspection. It is very important to take all these elements into account, although they are not structural elements, because they can affect to structural durability and to structural stability. As we said in section 2 of this article, Materials and Methods, viaduct had auxiliary metallic elements installed. In addition to the metal walkways previous mentioned, there are other metal elements such as lampposts, railings, supports for the pipes passage or supports for the installations passage. Most of these auxiliary elements are metallic elements. The metal of these metallic elements can corrode, just the same as steel bars of reinforced concrete can corrode [34]. Thinking that being external to the structure has no structural impact is a terrible mistake. All these auxiliary elements corrosion can spread to the interior of the concrete and deteriorate it, by corroding the steel inside it [22,23,27]. For this reason, during the inspection we paid attention to the corrosion of elements external to the structure present on the viaduct (Figure 9, Figure 12 and Figure 13). The corrosion of some metallic elements external to the structure was considerable. This damaging process must be monitored. A drone is of great help for the visual control of this deterioration, as we have shown here (Figure 12).

The photographs that will be taken in future inspection campaigns, which can also be taken with a drone, will allow us to analyze the evolution of the damage. With them, we will be able to analyze if the corrosion is advancing or if the corrosion has stopped. If the corrosion advances, treatments will be necessary to stop this advance. Corrosion can cause structural problems if its progress is not stopped in time [23].

In some of the piers, we detected defects related to the hardening phase of concrete. It means that, whatever reason, the concrete had not set or hardened properly during construction (Figure 15). These phases, the concrete curing phase and the concrete hardening phase, are particularly critical moments [35].

However, despite its importance, builders do not always pay the utmost attention to it. It happens not only in construction phase: it also happens in the possible subsequent repair phase and in the possible subsequent reinforcement phase. One of the reasons to inspect this viaduct was this: this structure was repaired and it was reinforced too [11]. It made it very interesting for this investigation.

During the hours immediately after concreting (between 2 hours and 10 hours), the concrete, still fresh, suffers plastic settlement, suffers plastic shrinkage and suffers superficial drowning. The hydration heat causes During the hours immediately after concreting (between 2 hours and 10 hours), the concrete, still fresh, undergoes plastic settlement, undergoes plastic shrinkage and suffers from superficial drowning. The hydration heat generated by the cement paste (that makes up the concrete) setting causes this damage [21,22,35].

Figure 15: Fissuring on the Map that Denotes Injuries Due to Plastic Shrinkage, Hydration Heat or Suffocation (Photograph Taken with the Anafi Parrot Drone)

The plastic settlement is the process of consolidation of the fresh concrete mass that settles, after having been vibrated and already reached the state of rest. Thus, concrete begins to settle: a component of concrete with less specific weight, water, migrates towards the surface. The concrete mass descends little by little; while the steel bars, placed and fixed before concrete pouring, tend to remain in their original place. Fresh concrete tries to descend and steel prevents it. Concrete under the steel bar sags and a discontinuity appears [36]. That discontinuity becomes a fissure or even a crack. That fissure or crack follows the direction of the steel bar.

The plastic shrinkage of concrete is a phenomenon of loss, by evaporation, of water not chemically combined and occurs when the concrete has not yet finished hardening. The use of the drone in this phenomenon is very useful and interesting. Plastic shrinkage is a very difficult damage to observe in slabs. But this does not mean that it does not exist in bridges like the one analyzed here. The difficulty of inspecting elements of the slab justifies this difficulty. However, it can also occur in abutment facings, in abutment accompanying wings or in large piers, as is the case here.

Finally, the chocked is the defect produced during the hardening of the concrete on the smoothest surfaces of the pieces. It occurs on horizontal surfaces and vertical surfaces. Its identification leaves no doubt thanks to the “crocodile skin” cracks or the “map cracks” (Figure 15). This injury is related to the initial shrinkage and is related to the setting heat. It usually appears in highly trowelled concrete or in elements whose formwork has been waterproof.

All these injuries are ugly: the damage is mainly cosmetic. They do not compromise the structural safety of the structure. However, they can cause durability problems in the structure, especially in the element that appears. These cracks are a risk for the durability of the steel bars and for the mechanical bonding behavior between these bars and the concrete, because the cracks are aligned with the bars. This circumstance forces special precautions to be taken in areas of medium or high aggressiveness. The first step is routine control, something the drone is very useful for. The drone allows the capture of a photograph in each flight, so that the evolution of the damage can be visually compared.

The use of the drone allowed access to the interior of the deck-beams assembly (Figure 16), to be able to observe the parts of the beams not visible from the outside (Figure 17).

At the ends of the lower flanges of some beams, slight chipping or chipping was detected, unimportant, beyond having left the prestressing reinforcement exposed (Figure 18 and Figure 19). They are probably due, if they have any structural explanation, to adherence failures of the final coating mortar. Its possible evolution should be checked in successive subsequent inspections.

Chips are a very common damage to concrete elements. In principle, this damage has no structural significance. Not so durability: if a chip is large, it becomes an access for external agents that can corrode the steel.

Many times, it is due to clumsy or premature stripping (because the concrete is not too strong enough) or steel bars insufficient covering. When the structure is built in a place where the temperature are usually low, as was the case of the inspected viaduct, the concrete hardens more slowly than in hot areas. For this reason, builders have to be more patient and careful in cold areas; if they are not patient, chips may appear.

Figure 16: View of the Drone Approaching the Space between Two Beams, for the Analysis of the Non-Visible Faces of the Beams (author's Photograph)

Bridge bearings observation is essential to verify no displacements. A displaced support or an excessively deformed support is due to design or execution errors. These errors force the bearings to adopt positions they are not intended for, or even support loads much greater than those initially projected [37]. The origin of a displaced support can also be due to movements of the foundation (seating of the pier or abutment or twists of the pier or abutment).

When a displaced bearing is discovered, an inspection has to define the location of the bearing devices and the constraints that these bearings absorb. In the same way, it is necessary to identify the local damage in the areas of these bearings. A drone can help us to carry out all these operations.

Figure 17: View Under the Deck of the Structure Towards Madrid, in Which it is Observed, in Addition to the Interior Faces of the Prefabricated Beams and the Precast Slabs, the Support Devices Under Some of the Beams (photograph Taken with an Anafi Parrot Drone)

Figure 18: Detail of One of the Beams, Where the Chipping of the End of the Wing Area can be Seen, Leaving the Prestressing Tendons Exposed (Photograph Taken with the Anafi Parrot Drone).

Figure 19: Two Beams Detail, where two Chips can be Seen at the Ends of the Wing Area, Leaving, as seen in the Beam on the right, the Prestressing Tendons Uncovered (Photograph Taken with the Anafi Parrot Drone).

The case of spalling at the bottom of the beam section is different. This chip appears at the anchor point of the passive reinforcement, when it is a reinforced concrete beam or it appears at the point where the prestressing coupler is located, when the beam is prestressed (as was the case with the beams of this viaduct). Occasionally, horizontal fissures parallel to the path of the tendon appear instead of these chips [21,22].

Among the causes of this type of injury, as has already been pointed out, are the lack of adherence between the concrete and the steel or the failure of the concrete due to exhaustion in the area of the hook of the tensile bars [38]. Similarly, excessive prestressing of the tendons or splitting in prestressed members with prestressed reinforcement or crushing in post- tensioned reinforcement can justify such injuries [21,22].

Its possible evolution should be checked in successive subsequent inspections. For this, the drone could be an element of undoubted utility.

The most noteworthy damage of all those that have been detected has been, with no doubt, the diagonal cracks that, on the face of the web of some of the beams, have been observed in the vicinity of the support (Figure 20). The structural origin of these cracks must be found fundamentally in the shear stress, although it could be accompanied by assembly or transport torsion of the piece [21,22]. Beams shear stress measures the bending moment variation along the beam directrix [39]. A deeper analysis of this crack would reveal whether it is a symptom of a loss of safety level, in order to reduce the structural significance of this damage [40].

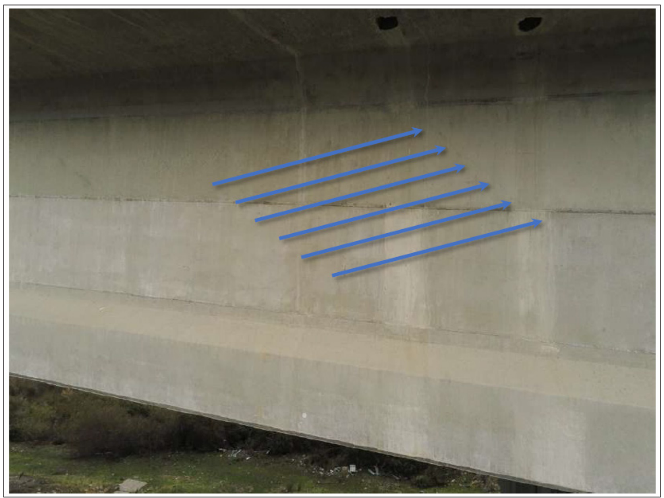

Figure 20: Diagonal Crack in the Beam Web, Caused Presumably by a Shear Stress (Photograph Taken with an Anafi Parrot Drone).

When a crack of this type is observed during an inspection, support devices should be sought as soon as possible. A detailed visual inspection of the beam in all the visible faces is necessary, and the drone can carry it out perfectly, as has been stated here [41]. A clear definition of the static scheme of the complete slab and of the section under study is precise, because this damage can be important: the associated failure mode could lead to sudden collapse, without warning [21,22].

Discussion

The previous sections have exposed the carrying out of a reconnaissance technical inspection on a viaduct. Routine inspections or main inspections, especially detailed main inspections, require a visual check, by a specialized operator, of all visible elements of the structure, whether they are accessible or not. This condition of inaccessibility can lead to the need to use extraordinary means of access, which guarantee the inspection of every visible parts (Figure 21, Figure 22 and Figure 23).

Figure 21: Main Inspection on the San Isidro Bridge, in Madrid, using Specific Equipment to Facilitate Operator Access to the Underside of the Deck (author's Photograph)

These means of access are cumbersome, difficult to transport, economically expensive and, what is even more important, their use always poses a risk to the safety of the worker who has to use them or climb on them in order to access those parts of the structure that, although visible, are more difficult to access. Indeed, visual inspections of structures, when carried out directly by personnel, usually require the use of mobile work teams that move people to a certain position, which allows the inspection to be carried out.

The use of these auxiliary means implies the coexistence of workers with risks such as falling to the same or, above all, to a different level, the equipment overturning, the fall of materials on people or goods, blows, shocks or entrapment of the operator or of the machine itself against fixed or mobile objects; entrapment between any of the moving parts of the machine's structure and between it and the chassis, to name just a few examples. Practically all of these risks disappear when the inspections are carried out with drones, the case of falling from a height being especially significant for this purpose, as it is unnecessary for any operator to have access to this type of auxiliary means or have to go down to access to complex points.

Figure 22: Main Inspection Under the Deck of a Viaduct that Crosses the Rías Bajas Highway (A–52), in the Municipality of A Gudiña, in the Province of Ourense, in Spain (author's Photograph)

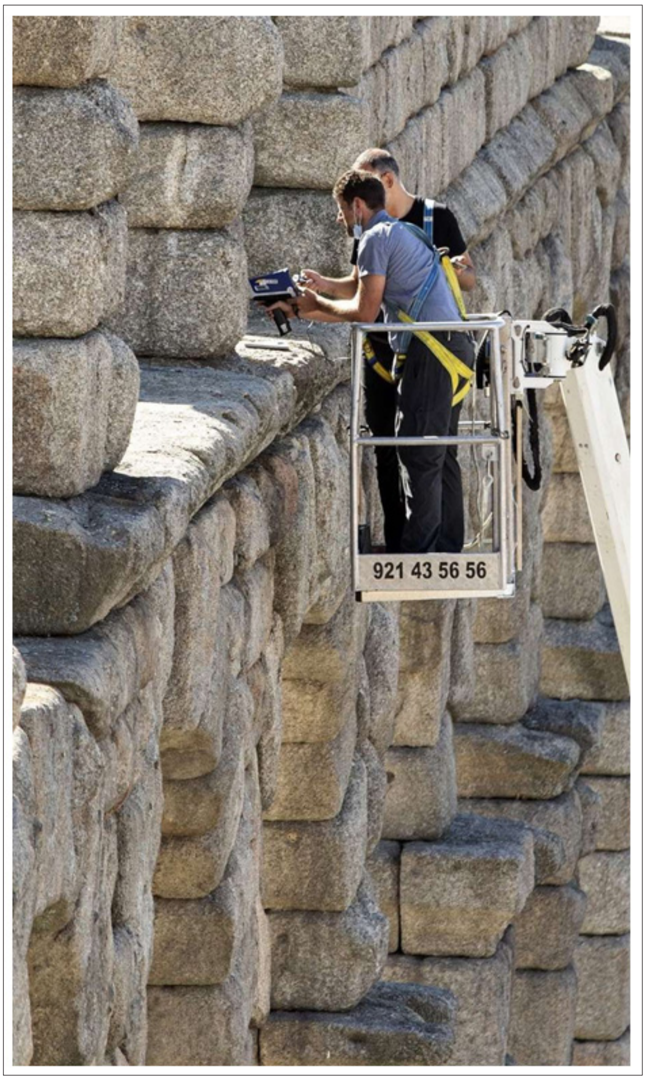

Figure 23: Image of a Check-Up Inspection (Special Inspection) of the Segovia Aqueduct: Two Workers from the Spanish Geological and Mining Institute (IGME) Take Data from Granite That Makes up the Stone Ashlars for its Geochemical Characterization (Photograph by Rosa Blanco) [42].

Needless to say that the experience of the experimental inspection carried out for the elaboration of this article can be extrapolated to many other identical nature works, as the next photographs prove (Figure 24, Figure 25 and Figure 26): inspection of buildings, old structures, industrial constructions or energy facilities, which opens up an infinite range of opportunities for these small ingenuities that, without a doubt, have come to stay and change our lives.

Figure 24: Transformation and Control Center Roof Inspection in a Wind Farm Located in Torre de Moncorvo, Bragança (Portugal) for the Location of Deficiencies Causing the Humidity Recorded Inside (Photograph Taken by the Author with an Anafi Parrot Drone).

Figure 25: Quadrotor Drone Flying in a Wind Farm Located in Vieira do Minho, Braga (Portugal), for the Inspection of the Nacelle and the Blades in One of the Wind Turbines (author's Photograph)

Figure 26: Electrical Substation Roof Inspection in Cinfães, Viseu (Portugal) to Verify Damage after a Heavy Hailstorm (Photograph Taken by the Author with an Anafi Parrot Drone).

Conclusions

Thanks to the visual inspection carried out with the drone, we were able to have a complete photographic report of all the visible elements of the structure. This photographic report has allowed us to diagnose all the injuries suffered by the viaduct. Fortunately, none of these deficiencies are serious and there is no safety hazard to the structure. The photographs can now be stored and used as a reference for future inspection. With the photographs of future inspections, we could analyze the evolution of the damage detected or diagnose the appearance of new damage.

The inspection results shown that the use of a suitable drone allows perfectly detailed visual observation of every visible elements, accessible and non-accessible, that form a structure of a certain entity, such as Viaduct La Jarosa. With this tool, it has not been necessary to resort to extraordinary means of access, as if they would have been necessary if the drone was not available.

Therefore, based on the experience gathered here, the following conclusions can be drawn:

1. The drone simplifies planning work, because it reduces the planning and acquisition of auxiliary means of access.
2. The drone simplifies fieldwork, for the identification and assessment of deterioration of each of the constituent elements of the structure.
3. We can work faster thanks to the two previous simplifications.
4. The drone reduces a lot of risks for the safety workers who should collaborate in the inspections. We must think in the danger inherent to the use of certain auxiliary means to access to certain structure elements: with a drone, no worker has to, for example, exposing them self to the risk of falling from height.
5. The four previous points justify a considerable economic saving, which does not imply a decrease in the work quality.

With the data collected with the drone, as this article exemplifies, a complete technical report of the main inspection can be generated in the cabinet, in addition to supplying the relevant information for its incorporation into a management system and obtaining the indexes of condition, of each one of the elements and of the structure as a whole, to assess whether some type of urgent action is necessary or whether, as in this case occurs with practically all the injuries detected, a periodic check of the detected lesions.

Only one of the many possibilities that these small devices offer has been exposed here. There are many other possibilities, many others may be the functions that they satisfy... Many others are, therefore, the future lines of research that open up with these intelligent tools.

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