STABILITY ANALYSIS FOR THE ROCK BASEMENT OF THE CASTILLO DE LOS TRES REYES DEL MORRO, LA HABANA, CUBA

Michele PARADISO ANTONELLI (*), Gianluca USELI (**), Francesco FIDOLINI (***)

(*) Dipartimento DiDA sez. Costruzioni, Piazza Brunelleschi 6, Firenze, Italia, +390552756852, michele.paradiso@unifi.
(**) Dipartimento DiDA sez. Costruzioni, Piazza Brunelleschi 6, Firenze, Italia, +390552756852, uselig@libero.it
(***) Dipartimento di Scienze della Terra, largo Enrico Fermi 2, Firenze, Italia +390552757784, francesco.fidolini@unifi.it

Abstract

Perhaps the best known castle of the Antonelli, in Havana, has been suffering for a long time the effects of deterioration of both of a material and structural nature. Various fissures and cracks can be found in the massive walls and in the vaults which, due to lack of conservation, to the action of the sea, and, on occasion, also to hurricanes and tropical storms, risk compromising the overall stability of the Fortress, and even threaten to undermine the foundations. This paper proposes a technique for the consolidation of the terrain, in order to safeguard the monument and its visitors.

Key words: Havana, Antonelli, terrain instability, cracks, consolidation

Resumen

Quizàs el màs conocido Castillo de los Antonelli, en La Habana, hace tiempo sufre por diferentes degradaciones de caracter matérico y estructural. Se encuentran en las poderosas murallas y en las bòvedas varias fisuras y grietas. Sobre esas ya los autores han contado en precedentes ocasiones. La presente ponencia relaciona sobre una importante situaciòn estructural que, por falta de manetenimiento, por la acciòn del mar, en ocasiones tambièn de ciclones y tempestas tropicales, tiene el riesgo de comprometer la estabilidad global de la Fortaleza. De hecho se abriò una profunda grieta en la roca adonde apoya la masa de la Fortaleza, hasta pensar que pueda agredir su cimentaciones. La ponencia propone una técnica de puesta en seguridad del terreno, para la salvaguardia del monumento y de sus visitantes.

Palabras claves: La Habana, Antonelli, instabilidad del terreno, grietas, consolidaciòn

Forward

The Castillo de Los Tres Reyes del Morro (Fig. 1) is, for its citizens, still one of the most recognized symbols of the city of Havana. For Cubans, the Morro is the imposing fortress, that with its lighthouse, visible from anywhere in the city and in particular from the very popular Malecón, overlooks the access channel to the port of the large bay. Built between the late sixteenth and the first half of the seventeenth century by the Spanish Crown, it is part of the complex system of fortifications built to defend the then important colony. It was commissioned from the illustrious military engineer of Italian

origin (Gatteo, Emilia Romagna) Battista Antonelli. He was one of the six members of the family of engineers who devoted themselves for nearly a century to the service of Spain and became

protagonists of an impressive number of works for war purposes, between fortresses, city walls, navigation of rivers, bridges, aqueducts, to real urban city plans. Their scope is incredible when we think back to the period they were working: Spain, North Africa, Central America from Panama to Veracruz, from Cuba to Cartagena de Indias to the coasts of Venezuela and Brazil. They were certainly not alone, but it is significant that Battista was directly appointed by King Philip II, in the late sixteenth century, to direct the overall project of the fortification system of the entire area of the Caribbean. The Morro Castle in Havana, according to most historians and international scholars, is the most important work of Battista Antonelli, representing the model of military architecture called *the modern*. It has its origins in Italy during first half of the sixteenth century with the founding fathers, the Sienese architect Francesco di Giorgio Martini and the Florentine Giuliano and Antonio da Sangallo.

Figure 1 – Location of the Castle Tres Reyes del Morro in the city of Havana.

The construction phases of the castle

Work started on the Morro Castle under the direction of Battista Antonelli and Juan de Tejeda on the 20 September 1589 as evidenced by the precious inscription on the stone near the “Platform of Estrella", the battery by the sea. The function of the fortress was to protect the city and the many Spanish fleets laden with merchandise that passed through the large bay, used from the start a natural harbour, from the repeated and threatening incursions of privateers financed by the British and French governments. The entrance of the access channel to the port was the strategic point of defence, and Antonelli was the first to design such an imposing fortified system in the city: the Morro Castle on the headland of the north shore and the castle of San Salvador La Punta on the opposite bank. The two forts were functional to each other, connected by a chain that controlled the port traffic and, if

necessary, assured the crossfire against enemy ships. For the Morro, Battista Antonelli envisaged a building constructed out of limestone extracted from the nearby Cabaña quarries, and because of the rocky nature of the terrain the building fits on a slope descending towards the sea in an irregular polygon plan, created to defend three lines of attack: the land front, the sea front and the harbour channel front. The construction technique adopted for the building of the fronts was that of *terreplein* although in most of them vaulted interiors were obtained and used as dwellings, powder stores and casemates. The land front (east) is the most regular, where the dictates of Renaissance Italian architecture are recognisable: It is made up of the curtain wall connecting the two side bastions, the moat, the counterscarp, the walkway covered with redan and the rampart. The two bastions (Fig. 2) are equipped with curved walls or with covered sides inside each of which were created a casemate with two embrasures to protect the curtain wall and moat. The bastions are named Tejeda (actually a demi-bastion) and Austria. The deep moat was designed to remain dry. The sea front (north-west) is characterized by an irregular curtain wall, which in plan forms a broken line with three points (vertexes) reaching out to the sea. This part of the wall connected the tip of Morrillo with its watchtower to the batteries of San Nicolás and Santo Tomás, which stood out from the demi-bastion of Tejeda. The harbour channel front (south-west) is opposite the la Punta castle and contains the main entrance to the fortress. This defensive front is made up of the Austria bulwark front, and faces south, continuing with a curtain that ends in the small, demi-bastion of Santiago. The front ends at the tip of Morrillo. Below the latter there is the "Platform of Estrella". The castle was equipped with three water tanks, essential for the survival of the troops during the sieges. All elements of the fortress were connected to each other according to a precise organisation of connections, stairs and ramps and secret sorties to the outside. The interior of the fortress, the parade ground, was an area designed to be occupied by a sort of citadel, made up of several buildings with temporary structures intended to accommodate the troops and the commander, a church and some warehouses. The actual parade ground, a place necessary for the gathering of the troops, was between the curtain wall of the main entrance and the citadel itself. All around the complex of buildings was the patrol path and the two ramps leading to the high platforms of the castle. The construction of the Morro Castle, which lasted for a long time, was finally completed throughout in 1640: for over a century it was one of the most important overseas fortresses ensuring the impregnability of Havana. With the participation of Spain in the Seven Years War, Havana was attacked by the British in June 1762 and conquered a few months later, just after Morro Castle was taken. During the siege, although the main body remained intact, the fortress suffered some destruction as a result of mines, mainly on the land front: the curtain wall, the Tejdea bastion and the San Nicolas battery. When the city was returned to the Spanish, the new government began a series of reforms that led, among other things, to the renovation and rebuilding of the city's defence system, and work fell to the Spanish engineer Silvestre Abarca, assisted by Augustin Crame. Among the various works proposed, a significant decision was to build the imposing castle of San Carlos de la Cabaña (1763-1774) on the same named hill, near the Morro, which removed its primary importance in the defence of the city. On the other hand, the decision to

reorganize the existing fortresses, including the Morro, confirmed their strategic importance despite the added limitations that appeared with the evolution of military techniques. In a short period of time (1764-1771) the destroyed parts of the castle were rebuilt and provided with greater solidity and the functionality of the building was improved by the inclusion of new elements such as the central building, the new ramps, the Santo Tomás battery, the tunnel with arrow slits with covered walkway that connected it with the new Cabaña fort, the deepening of the moat, the reconstruction of the ancient tower and so on.

Figure 2 – The elements and areas of the fortress complex that are preserved today.

Recent history

During the following centuries the castle retained its new eighteenth century shape, not far from the original, at least as long as it had its military defence purpose. With the approach of the Hispanic-American conflict at the end of the nineteenth century, the Velasco battery was built to strengthen the northern part of the sea front as well as a series of minor adaptations, such as the insertion of the powder magazines and the new modern cannons. Also in the nineteenth century its role as a maritime traffic station was strengthened with the complete reconstruction (1844-45) of the lighthouse and the commissioning of the first semaphore station (1888), later rebuilt in the following century (1926). With the conclusion of the last military confrontation, the rooms of the castle hosted the first Army Cadet School (1911-45) and then, with the advent of the revolutionary movement, a prison (1967). In

1977 it was decided to transfer the prison from Morro to concentrate everything in the fortress of San Carlos de la Cabaña. At the same time Eusebio Leal Spengler, historian of the city of Havana, proposed Morro as the place to host the XI World Festival of Youth in the following year, thereby allowing the spaces to be opened for the first time to the public, sanctioning the cessation of its use for military and para-military functions. The Ministry of the Armed Forces of Cuba (MINFAR) entrusted the management of the commercial enterprises that took place within to one of the many local tourist-food businesses. With funding obtained from the Youth Festival a series of initiatives were set up for the redevelopment of the area that were initially entrusted to an outside state company, the Empresa Nacional de Obras Arquitectónicas (ENPOA), which, in 1982, was given the job of opening up the complex. Furthermore, 1982 was a pivotal year for the city and its monuments - including the Morro Castle - as it was included in the UNESCO world heritage list and declared a World Heritage Site. From this time on international organization sent many funds to restore the historic centre of Havana and the fine military works. The Oficina de l'Historiador de La Ciudad (OHC) directed by Eusebio Leal, took over ENPOA, from whom it inherited the documents and on the basis of which worked out a programme of restoration for the castle, which took place between the years 1987 and 1993. In 1992 the local authority of the Park of the historic military complex of the Morro and the Cabaña (PCHMC) was established. The he project idea was born to recover the fortified complexes and organise a wider surrounding area. In 1993, after the conclusion of the restoration work, it was reopened to the public and regularly hosts important events: the Art Biennale in May and the Book Fair in February. At that time MINFAR also took charge of the entire management of space through an administrative body within the Military Historical Museum Complex (CMHM), thus concluding the contribution of the OHC. In early 2000 the CMHM decided to invest and restore the two fortresses within a larger programme. An internal technical department was instituted within it and work began in 2007, giving priority first to the rooms of the Cabaña, and in the following year to Morro. The restauration is still continuing, although the complex remains partially open to the public for visits. The Castillo de los Tres Reyes del Morro is still one of the most recognized symbol of the city of Havana. The view of it, especially at sunset, is very impressive: the semaphore station with its lighthouse performs the task of strategic control of all maritime traffic in and out of the port of Havana. From its summit, it is possible to identify all areas into which the city is divided. In addition to its function of maritime surveillance, the Morro Castle makes some of its many spaces available for artistic or cultural exhibitions. The main access to the complex is the "Bay Tunnel", only for vehicles, which runs under the channel and connects the two shores of the bay. For visitors this trip is generally done by taxi or tour bus that makes its first stop at Morro before continuing to the seaside resorts of the east coast. The famous "Lanchita", the boat that still crosses the bay to daily link the Habana Vieja to the opposite banks, allows you to reach the village of Casablanca, from which you can then reach the Morro Castle along a walking trail.

State of conservation

The complex is preserved intact although the state of environmental, material and structural degradation present some emergencies of no small importance (Fig. 3). The restoration at the end of the last century, although started with very different intentions, involving the entire area of the Military Historical Park, basically allowed it to be sufficiently usable, almost throughout, for visits by the public. Unfortunately, the restoration was never followed up, and combined with the lack of funds for maintenance, the situation has not improved. Only recently, since 2008, has the CMHM resumed restoration work, both at the Cabaña and the Morro but, however, has only managed to intervene with specific operations targeted to certain areas and lacks a comprehensive plan of the work to be done.

The rooms of the castle suffer greatly from the presence of moisture with a high salt concentration, which attacks the surfaces and materials causing widespread erosion of stonework, forming biological patinas, disintegration and detachment of the surface layers such as plaster. In many indoor environments, especially the less ventilated ones, there is the formation of saline concretions in the form of stalactites and stalagmites. The erosion is then accentuated by being highly exposed to strong winds and storm surges produced by cyclones, which cause the waves to violently crash onto the outer curtain wall and even to penetrate the complex. Just think of the conditions in which its inscriptions find themselves, those that attest to the laying of the foundation stone and among the oldest on the island. Their long term conservation is in absolute danger with sea water slowly eroding the relief, especially on the right part, where it is already compromised in many areas. In recent years, the conditions have been getting rapidly worse and yet no remedies for this problem have been put in place. To this situation can be added the lack of maintenance and safety of the spaces, where machines and bare wires are often found and there is frequently a lack of adequate protection for visitors. Furthermore, the monument and its spaces are poorly appreciated, starting from the lack of connections to the city. From a static point of view emergencies that deserve immediate attention concern the rocky base of the cliff, on which the castle rests, which presents a series of fractures along almost the entire perimeter as shown by a geological study carried out in 1989, which has never been followed up by a consolidation project or specific interventions. One of these fissures, to the side of the Estrella battery and below the Morillo point, has an opening of about one metre that goes inwards and stops before the beginning of the fortress' wall, which for now shows no visible instability. However, the depth of the crack together with the effect of the disintegrating action of sea could lead to serious problems of the complex's stability. Another concern is the condition of the sentry post at the summit of the Santiago bastion, the only part of the complex to keep the original eighteenth-century reconstructions and which so far has resisted damage or collapse, unlike the other three in the complex. Its wall has some fractures where it connects to the parapet: it can be seen that the fracture passes right through, from inside to outside to the side of the entrance but there is an important problem also on the other side, while the attachment of the sentry box to the base is not particularly unstable. This situation places the structure in serious danger as although the upper part, formed by the perimeter walls and dome, is firmly attached to the base, it is without - or at least limited in- the

necessary horizontal connections, that would ensure an adequate bond to the masonry. This situation can lead to the formation of an ideal joint at the base of the attachment that, under the weight of its own cantilever volume, as well as the horizontal action of the wind and rain produced by cyclones, could overturn the element itself, and lead to its collapse. The situation calls for urgent action, not just to safeguard a valuable element of the fortress, uniquely original in its kind, but also to avert serious injury to people. Finally, the presence of some fractures in the vaulted brick tunnels of the central building raise concerns for their size and because the problem has not yet been analysed with due attention.

Figure 3 – Some current emergencies of degradation by various causes: environmental, material and structural deterioration

Geo-lithological context

The bedrock on which the Morro Castle stands is made of organogenic limestone of Pliocene to Pleistocene age (ENIA, 1981). In the southern and lowermost part of the cliff the Morro Formation (Pliocene) is exposed. This limestone has a light grey to white color, is medium- to fine-grained and shows a rough stratification; beds are about 30 cm thick and their dip is 350/10. The Vedado Formation (Early Pleistocene) lies conformably above the Morro Formation and is exposed in the northern part of the promontory. This unit is made of white, fragmented limestone with abundant remains of corals and mollusks. These rocks show a macroporosity and constitute the main part of the Morro ness. The southeastern margin of the promontory is draped at the base by cemented debris of limestone belonging to the Jaimanitas Formation, with a sub-horizontal attitude. All the rocks exposed in the area are fractured and the majority of these fractures are filled by a cemented fine-grained

breccia made of limestone and shell fragments. Calcareous, red cement incorporates the clasts. In many parts of the promontory this breccia is eroded in its surficial portion. The cliff rests on the uplifted side of a crack located along the Habana Harbor channel.

Fracturing conditions of the rock mass

According to the available data (ENIA, 1989) the rock mass shows a significant degree of fracturing, which is higher in the Vedado Formation than in the Morro Formation.

The discontinuities can be grouped in three main systems (Fig. 1; ENIA, 1981). The first one (S1) is represented by bedding (350/10). Bedding planes are rough, undulated and frequently draped by a 1 mm thick layer of calcite. The spacing between beds ranges between 20 and 60 cm.

The second system (S2) is perpendicular to bedding and is represented by fractures oriented 170-180/70-90 (or 350-360/70-90). These discontinuities show openings ranging between one few mm and several cm. The tightest ones are commonly gaping, while the widest ones are usually filled by the abovementioned breccia. The spacing of discontinuities belonging to this system is about 60-100 cm.

The third system (S3) of discontinuities is related to fractures showing irregular, undulated and rough surfaces, with an orientation of 230-240/75-85. The opening between the planes is commonly higher than 5 cm and fractures are filled by breccia. The rock mass is also affected by several additional fracture systems of minor relevance.

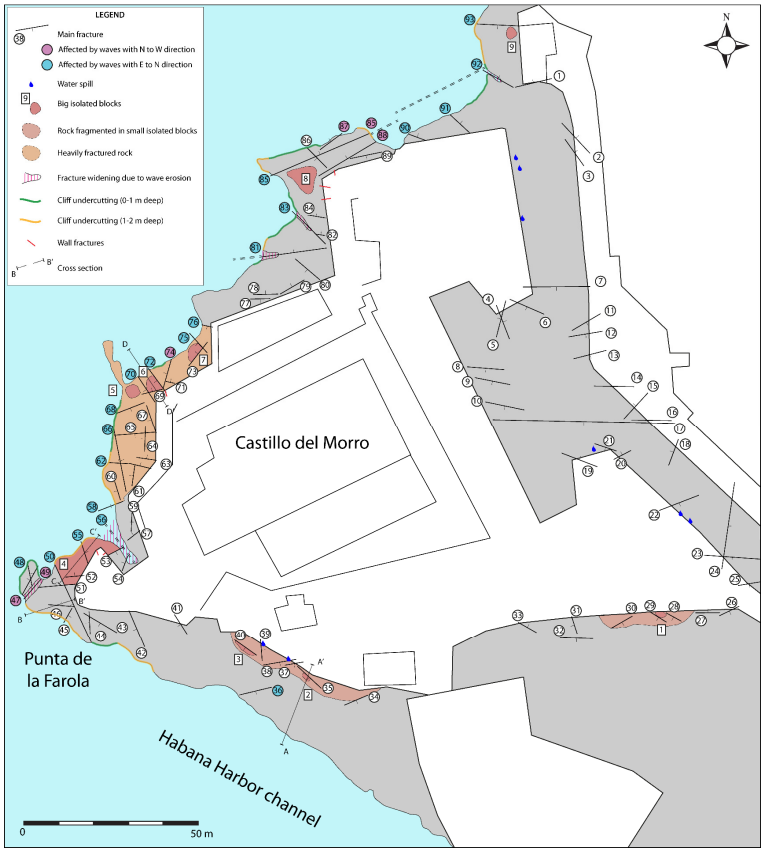

Figure 4 – Map reporting the main geological concerns of the Morro Castle promontory. Modified after ENIA, 1989.

Regarding the geotechnical concerns, the area can be divided in three sectors, according to the triangular shape of the promontory: 1) the eastern side, corresponding to the ditch area; 2) the southern side, facing to the Habana Harbor channel; 3) the northwestern side, facing to the open sea.

In Sector 1 (delimited by fractures #1 and #26) the lithological contact between the Vedado and Morro formations is exposed. This is mainly a plane area where, besides being fractured, the rock is also widely affected by karst phenomena up to an elevation of 6 m a.s.l. Both in the northern and southern parts of the ditch there are several fractures from which water spills. This is to be considered to plan the interventions for the reinforcement of the rock mass. In Sector 2 (bounded by fractures #26 and #48), where the beds are arranged anti-dip slope, there are some significant fractures that rise up to the base of the walls and need to be constantly monitored. This is the case of fracture #41, which was reported as possibly dangerous for the walls' stability by different authors (ENIA, 1989; report of Ing. Felix de la Noval Ravelo, 1997) and seems to have its natural prosecution on the other side of the promontory, with fracture #56. This sector is also characterized by the presence of two areas where numerous small isolated blocks, produced by rock fragmentation, concentrate: one in the eastern margin of the sector and one in its middle part.Besides these blocks of small dimensions, these areas present the occurrence of larger ones in critical positions (e.g. block n° 2 in Fig. 2). In proximity of fractures #37 and #38 water spills are present.

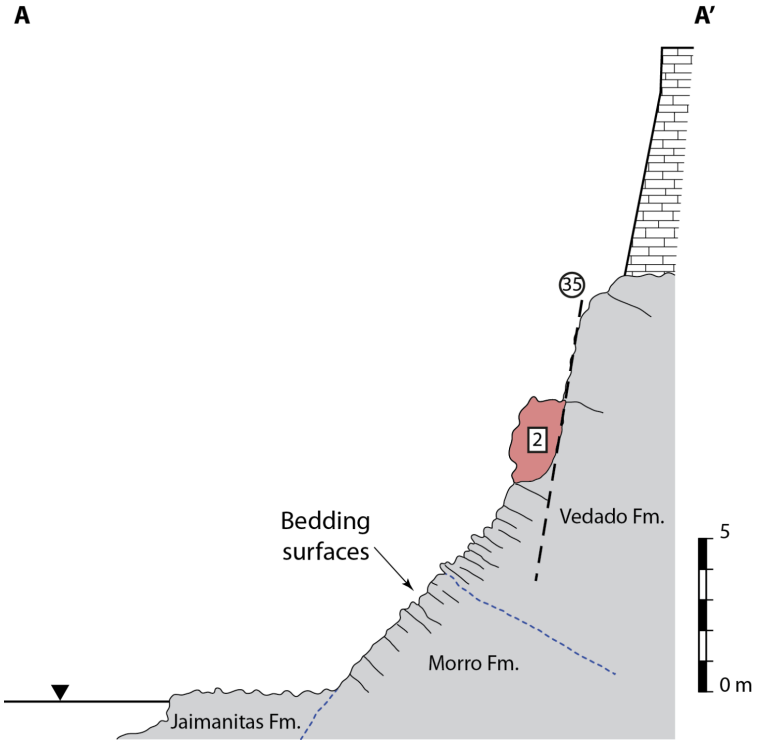

Figure 5 – Section A-A' along the southern margin of the promontory. Vertical and horizontal scales do not coincide, as the former is exaggerated. Modified after ENIA, 1989.

Moving towards the western margin of this sector, corresponding to the southern side of the lighthouse tip (Punta de la Farola), the slope presents some significant undercutting of the cliff due to marine erosion (ENIA, 1989), as shown in Fig. 3, and fracturing becomes more intense. These features are

probably related to the increasing strength of the wave action on the cliff, as long as it approaches the open sea. Sector 3 (comprised between fractures #48 and #93) appears to be that most affected by fracturing and marine erosion, likely due to its complete exposition to wave action. Most of the cliff is affected by undercutting and a relevant number of fractures extending to the sea level are significantly widened by erosional phenomena (Fig. 4). A huge block (n° 4, see Fig. 4), delimited by NW-SE oriented discontinuities (#50 and #56) on the sides and by a lithological contact below, rests in a critical position just below the walls. ENIA (1989) calculated that, despite its location, even storm events with a return period of 100 years (impact pressure of 0.14 MPa) couldn't put this block in unstable conditions. Nevertheless the walls resting just above this block present some fractures that need to be monitored. The portion of the slope comprised between fractures #58 and #76 is that one showing the most intense fracturing, which is mainly N-S and W-E oriented and gives to the slope itself a block structure. Many of the fractures are gaping and extend from the sea level to the foot of the walls. Some large size isolated blocks are also present and some of them appear in critical position, e.g. block n°6 (Fig. 5). Also in this case the wall resting on the slope behind the block shows a facture.

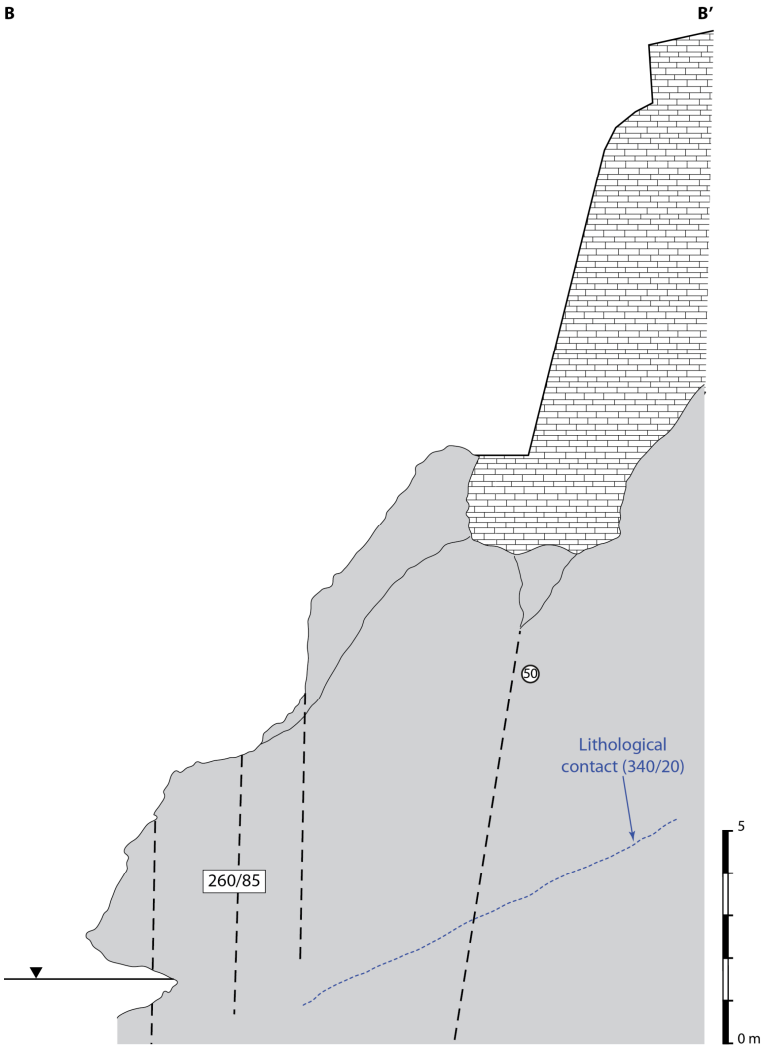

Figure 6 – Section B-B' crossing the slope of Punta de la Farola. Vertical and horizontal scales do not coincide, as the former is exaggerated. Modified after ENIA, 1989.

The northern part of Sector 3 (north of fracture #76) is affected by a minor number of fractures and presents many erosional and karst phenomena, such as surficial cavities of different size. Though fractures are persistent and wide.

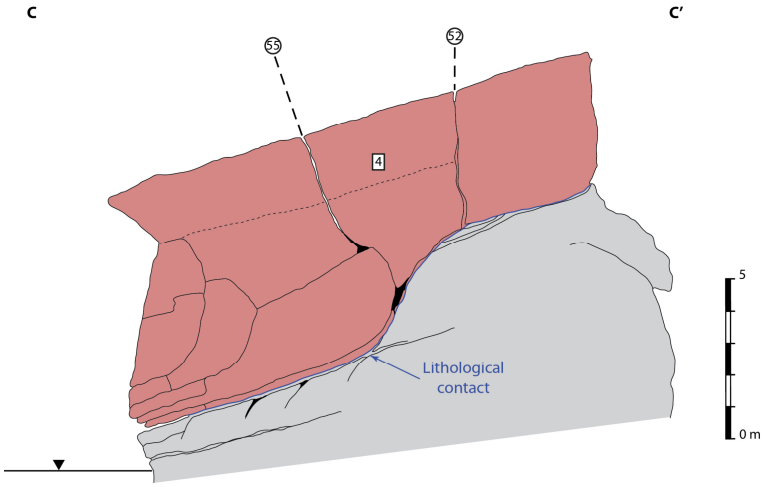

Figure 7 – Section C-CB' parallel to the northern side of Punta de la Farola. Vertical and horizontal scales do not coincide, as the former is exaggerated. Modified after ENIA, 1989.

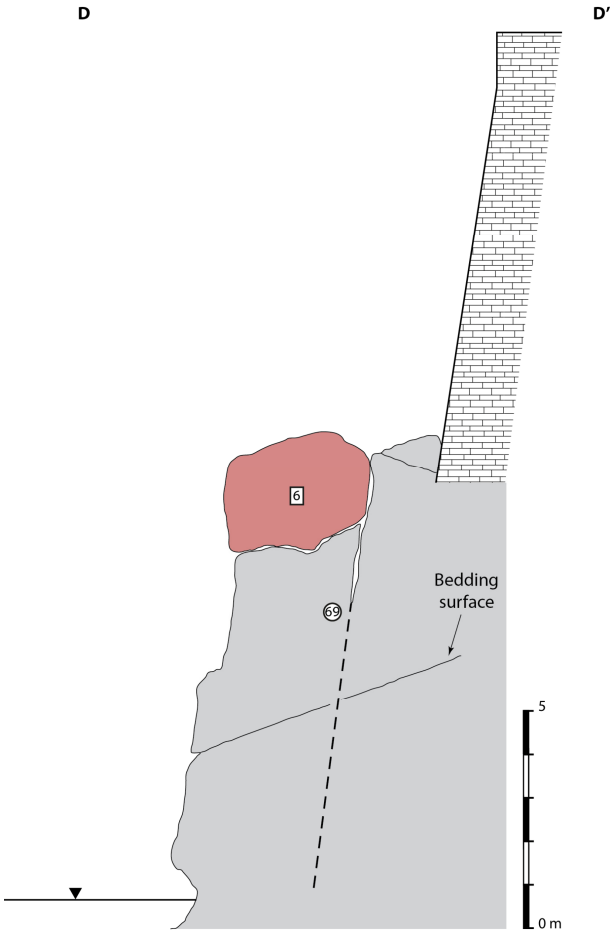

Figure 8– Section D-D' along the western margin of the promontory. Vertical and horizontal scales do not coincide, as the former is exaggerated. Modified after ENIA, 1989

Proposed mitigation measures

Since the stability of the Castle walls seems not to be significantly affected by the fracturing conditions of the rock mass, a multi-temporal approach can be suggested for the conservation of the structure. This approach must take into account a short-term and a long-term perspective, in order to face the priorities.

Short-term measures

In the short term the main concerns are represented by the slowdown of all those factors contributing to the weakening of the rock mass and to the decay of its geotechnical properties. Among those concurring factors, the most important is likely the wave action. The impact force of waves acting directly on the rocks must be reduced, especially in those areas where the width of the cliff is small and the walls of the Castle are closer to the sea (e.g. in the surroundings of Punta de la Farola and in different zones of Sector 3). To obtain this effect some dissipative structures are to be located seaward of the cliff. As the coast is quite steep, dropping down to -10 m a.s.l. few meters from the coastline, and the sea in front of the Castle is quite busy due to the proximity of the harbor, the creation of breakwaters or seawalls is discouraged, besides their high cost. A lower cost solution must be identified in the emplacing of stony barriers attached to the cliff (e.g. berms or revetments), starting with those areas where the undercutting of the cliff or the widening of relevant fractures is more pronounced (Fig. 6).This operation is to be accompanied by the filling of all those fractures considered as potentially dangerous for the stability of the walls (e.g. fracture #41), in order to reduce the surface available to the erosional action of waves and other weathering phenomena.

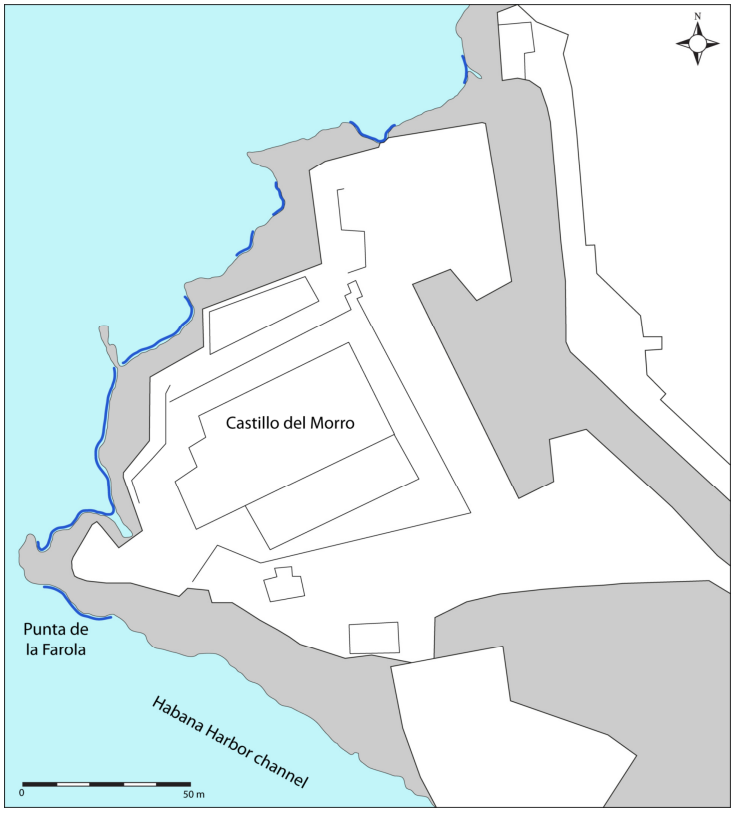

Figure 9 – Map reporting the proposed location of wave-energy dissipation structures.

Long-term measures

In the long term a new geotechnical and structural survey is obviously needed to update the information regarding the conditions of the rock mass and the buildings. Furthermore a more incisive reinforcement of the rock mass is to be taken into account, in order to preserve the promontory and the Morro Castle resting on it from future stability problems. Large blocks resting in critical positions (e.g. blocks n° 2 and 6) need to be stabilized, for example strapping them to the cliff by dowels and steel cables or chains;the small ones can be simply removed. Those portions of the cliff where fracturing is particularly pronounced and risk of toppling is high, due to a combination of fractures orientation, beds attitude and undercutting, need to be reinforced using anchors (e.g. the slope shown in Fig. 3) and locally accompanied by the construction of anchored retaining walls in case of overhanging slopes.A similar anchoring system should be used for the stabilization of block n°4, if the reassessment of its stability conditions will give bad results. Once realized the anchors, their conditions are to be constantly monitored, due to the particularly aggressive weathering that is expected. Because of its high cost and logistic issues, injection of the rock mass with consolidating mixtures must be considered onlyin case of extremely weakening of the rock mass due to fracturing and karst phenomena, but must be avoided in all those areas where water spills are documented (e.g. the western side of the ditch), in order to prevent uncontrolled alterations in water circulation.

Conclusions

In this period, after the inauguration of the new industrial port of *Mariel*, the Cuban Government is planning a new arrangement of the entire baya, to increase the tourist attraction. And we think that this can be a good occasion to resolve the various crises that presents the entire complex of Morro-Cabaña, includes the structural instability of the rock basement of the Morro Castle. Moreover the solutions proposed in this paper, at least those in the short term, are not very expensive and could be resolved with the strategies of international cooperation for human development.

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