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1. PURPOSE

The purpose of this report is to assess the benefits and possible shortcomings of the structural reinforcements carried out to hospitals in Costa Rica, in the light of the earthquakes that occurred there in 1990.

The report will also describe the difficulties that rose and how they were overcome.

A description will be provided of the type of reinforcement work carried out in each hospital, and the plans drawn up to carry it out will be discussed. The cost of the reinforcement work will be assessed in comparison with the hospital budget and the value of the building. A description of the losses that occurred in the hospitals that were not reinforced will also be made, to provide a yardstick for comparison.

2. INTRODUCTION

2.1 Seismic risk in Costa Rica

Costa Rica is a Central American country located between latitudes 8 and 11 degrees north and longitudes 82 and 86 degrees west. Its continental platform lies on the Caribbean tectonic plate, and its Pacific coast lies opposite the area of subduction where the Cocos plate slides under the Caribbean plate. This area of subduction is capable of generating earthquakes of up to magnitude 7.5 on the Richter scale, and of intensities up to VII on the modified Mercalli scale.

The collision between the plates results in countless faults on the continental shelf, which are capable of producing relatively shallow earthquakes close to towns, of magnitude 6 on the Richter scale and up to VIII on the modified Mercalli scale.

In Costa Rica as in the whole of Central America, seismic activity is fairly intense; as a result, monitoring, disaster-prevention and response agencies are on constant alert and are constantly reviewing and updating their procedures.

2.2 Previous damage to hospitals by earthquakes

Damage to hospitals was the main form of infrastructure damage caused by some of the earthquakes that occurred during the 1980s in Latin America. This was the case of the 19 September 1985 Mexico earthquake, which totally destroyed the Juárez hospital and completely devastated the Medical Centre.

On 10 October 1986, an earthquake of magnitude 5.7 occurred in San Salvador, reaching intensities of µp to IX at its epicentre. The earthquake was caused by local faults located under San Salvador, and peak ground accelerations of 0.47 g were recorded only three kilometres from the epicentre (0.47% of the acceleration of a free-falling body). These peak accelerations are one of the parameters used in structural design, and are a quantitative measure of the intensity of ground movement. The earthquake caused damage to 6 hospitals in the Salvadoran capital and reduced capacity from 2160 installed beds to 925 after the earthquake, i.e. 57% of installed capacity was lost. The disruption of medical care was enormous and immeasurable.

The earthquake that occurred on 3 July 1983 at San Isidro de Pérez Zeledón, in Costa Rica, is one example of a Costa Rican earthquake that was responsible for damage to hospital facilities. The 5.9 magnitude earthquake, caused by a local fault, produced intensities of VII (MMI) in the town of San Isidro, and of VIII in some surrounding towns. The that most heavily damaged public building was the Escalante Pradilla hospital, owned by the Costa Rican Social Security Fund (CCSS).

The hospital had been inaugurated in 1975, and was designed before the Costa Rican seismic code was promulgated. It had 210 beds and served a population of 110 000. There were serious deficiencies in its structure, making it highly vulnerable to earthquakes; in addition, incorrect anchoring and ties, and the fact that many of them were located in the same place made the electromechanical equipment unsafe.

The structural damage caused by the earthquake was caused by what is known as the short column effect, and was generalized throughout the structure. Enormous non-structural damage was caused to ceilings, windows and installations, leading to panic among staff and patients who fled from the building leaving equipment running and gas, steam and compressed air outlets open. The hospital ceased to function, and emergency care had to be provided at a field hospital.

The total cost of the repairs amounted to 25 million colones , i.e. US$ 500 million at the exchange rate of the time, and $2380 per bed was spent on repairs. The repairs were completed in July 1984, twelve months having been necessary before the hospital was fully operational.

2.3 Measures taken to prevent and mitigate seismic emergencies in Costa Rica.

In Costa Rica, since the 1930s legislation designed to reduce the impact of earthquakes on buildings has prohibited the use of adobe and *bahareque* (wood and mud) for construction purposes. Nevertheless, it was only in 1974 that the first edition of the Costa Rican Seismic Code was published; its purpose was to formalize the country's building procedures and designs.

The initiative of laying down a design and building code was taken by Association of Engineers and Architects in the light of events in Managua, Nicaragua, which was destroyed by the 23 December 1972 earthquake, and in Tilarán, Costa Rica as a result of the 13 April 1973 earthquake. The Code was updated, and a second edition published in 1986.

In 1977, the Economic Planning and Policy Office, the National Insurance Institute and the Association of Engineers and Architects ordered a "Study of seismic risk in Costa Rica" from the John A. Blume Earthquake Engineering Center at Stanford University. The study provided a basis for defining acceptable levels of risk in the second version of the Seismic Code.

In Costa Rica, there are monitoring and research units in the universities, which are assisted by international agencies; at present these units are responsible for updating information and for proposing norms to prevent and mitigate seismic emergencies.

In 1986, the National Commission on Emergencies was set up. The Commission not only deals with emergencies themselves. but also encourages national institutions to adopt preventive measures and provides advice on the implementation of plans for hospital care during emergencies. This has led to the establishment of emergency committees in all hospitals, most of which have plans of action for emergencies inside and outside the hospital. The emergency plans have been put to the test in four hospitals in the Metropolitan Area (the National Children's Hospital, the Mexico Hospital, the Calderón Guardia Hospital and the San Juan de Dios Hospital) and in two regional hospitals (Liberia and Los Chiles).

A basic plan for adoption by all hospitals in Costa Rica has been drawn up.

As far as plans to provide care during domestic emergencies such as floods, fires or earthquakes are concerned, almost every hospital has carried out a risk evaluation and has a fire brigade trained by the National Insurance Institute. Where earthquakes are concerned, risk assessment began in 1984 and the reinforcements began to be designed and built in 1987. At present, the National Children's Hospital has been completely rebuilt, while the Monseñor Sanabria and Mexico hospitals are being rebuilt.

2.4 Project to evaluate and strengthen hospitals

Risk assessment studies of hospitals in Costa Rica began in 1984 at the University of Costa Rica in the form of research projects and in response to growing concern in the hospital sector about a possible repetition of the events that occurred in 1983 at San Isidro de Peréz Zeledón. The Civil Engineering School decided to begin the task thanks to the encouragement provided by what was then the National Emergency Fund and to the interest shown by the political authorities and the Costa Rican Social Security Fund. The Pan American Health Organization's disaster office was one of the agencies which encouraged staff at the University of Costa Rica to start the process, which was a new field of research in Latin America.

After the study into the Calderón Guardia Hospital, in 1985 the University requested the National Council for Scientific and Technical Research (CONICIT) for funding to study the whole of Costa Rica's hospital system. CONICIT partly approved the request, and the University used the funds to study the seismic risk at the Mexico Hospital. One of the factors that secured the funding was the firm support of prominent physicians at CCSS for the project.

The Mexico Hospital risk assessment study was the first comprehensive seismic risk assessment carried out in Costa Rica, since it covered the different levels of structural, non-structural and operational risk affecting the hospital.

At the same time, CCSS, through its architecture and engineering department, signed contracts for risk assessment studies at the Monseñor Sanabria Hospital, in the town of Puntarenas and at the National Children's Hospital in San José. The studies were entrusted to private firms, and unfortunately the final reports from the studies are not yet available, probably on account on the institution's internal administrative problems.

The 1985 Mexico and 1986 San Salvador earthquakes were the catalysts that brought the region's political authorities face to face with the risks to which hospitals were faced, and which were described in the risk-assessment studies. In September 1987, the Government of Costa Rica issued a decree requiring all national institutions to carry out risk-assessment studies and to reinforce all their buildings if necessary.

After the risk-assessment studies, CCSS signed contracts with three different private firms for plans to strengthen the three hospitals referred to above; the firms imposed their own interpretation of the levels of risk and the appropriate response. These rebuilding plans were not incorporated into a master plan that would have determined objectives, allocated a budget and standardized levels of risk, entailing the danger of a lack of continuity, which is what in fact occurred. The projects were an institutional response to the results of risk-assessment studies and experience in neighbouring countries.

The reinforcement building work was contracted out by CCSS through a public call for tenders. The tenders essentially concerned structural reinforcement, and paid little attention to architectural and operational considerations; this caused financial losses during the building work, as will be shown later.

There are currently no diagnostic or reinforcement studies under way at existing hospitals, with the exception of those concerning reinforcement and repair of the damage caused by the 1990 earthquakes. A new hospital is even being designed without taking into account the non-structural and operational requirements of an earthquake-proof building. This is because of the current budgetary problems of CCSS rather than ignorance on the part of its officials, who have developed sufficient experience and knowledge of the risks that exist.

3. DESCRIPTION OF THE WORK CARRIED OUT IN THE REINFORCED HOSPITALS

The hospitals that have been reinforced since 1990 have already been referred to. Two of them, the National Children's Hospital and the Mexico Hospital, are located in the town of San José. A third hospital, the Monseñor Sanabria Hospital, is located in the town of Puntarenas on the Pacific coast. This part of the report concerns these hospitals, the way in which they have been reinforced and the impact of the reinforcement work on their operation.

3.1 National children's Hospital

This 375-bed hospital cares exclusively for children.

It comprises four separate buildings; the oldest of them a 1000 square metre three-storey building dating from the nineteenth century. It was not reinforced during the previous reinforcement work. The other three buildings, two of them five-storey and one a single storey building, were built between 1960 and 1964. As a whole, the floor area of the buildings is 16 000 square metres.

The value of the hospital is estimated to be 2 600 000 000 colones (US$ 23.6 million), and its annual budget amounts to 2 000 000 000 colones (US$ 18.2 million).

The reconstruction work on the buildings completed in 1960 and 1964 involved building walls or structural walls along the buildings' main lines of resistance. A diagram of this rehabilitation is given in figure 1.

It is important to point out that the rehabilitation required an almost complete reworking of the building's internal or external lines of resistance.

The building's original structure was based on columns and plain slabs, without beams. This made the building very flexible and subject to considerable lateral deformation during earthquakes. This caused major non-structural damage, and the possibility of a sudden structural failure could not be discounted.

The rehabilitation of the building limited its lateral displacements and consequently the non-structural damage; it also increased its resistance, thus eliminating the probability of a sudden failure.

The cost of the rehabilitation was 110 million colones (US$ 1 100 000), 65 million of which were for the initial contract and 45 million for additional work and costs. In other words, a total of 293 000 colones per bed was spent to improve the seismic safety of the hospital. This figure represents 4.2% of the hospital's total value. Section 3.4 provides other economic data comparing this investment with that in other hospitals.

During the rehabilitation work, which began in 1988 and lasted 25 months, hospital capacity was reduced to 30 beds and the hospital had to purchase surgical services from the San Juan de Dios hospital. Many of the services had to be provided at the National Rehabilitation Centre, with all the drawbacks that a partial transfer of the hospital entailed. Those services that continued to function in the hospital building had to put up with all the hindrances inherent in building work, such as noise, dust, changes in traffic etc. One drawback to which the hospital officials drew attention was the unwillingness of staff, and their occasional failure to understand or to cooperate to work under such conditions.

3.2 Mexico Hospital

This is a general hospital with a wide range of special units and services. It is also a referral hospital for all the hospitals in the western part or half of Costa Rica.

It has 600 beds and comprises three ten-storey hospital buildings, a four-storey surgical block and six buildings housing other services such as the outpatient clinic, machine room and laundry, etc. (see, fig. 2).

The hospital was designed by the Mexican Social Security Institute in 1962, and completed in 1969.

It has a floor area of 3000 square metres and cost 3000 million colones (US$ 27.3 million). Its annual budget is 3000 million colones.

Rehabilitation of the hospital complex was limited to the three hospital buildings, the surgical block, machine room and laundry.

The rehabilitated buildings were composed of not very ductile concrete frames (beams and columns), with walls made up of blocks integrated into the frames. The walls were not uniformly integrated, nor were they integrated to the top of the columns, thus jeopardizing the resistance and stability of the concrete frames Two emergency staircases in the building are located at the end of the hospital buildings. The staircases were of cantilever wall construction, resting on a single base plate, which made it very likely that they would topple like rigid bodies during an earthquake. This type of structure had already been observed to behave in this way during previous earthquakes.

Rehabilitation of the three hospital buildings basically involved placing additional columns and beams along the outside of the concrete frames and uncoupling all the walls from the structure. The walls of the emergency staircases were also tied to the building structure to prevent them from toppling. These structural changes increased the building's rigidity, implying a decrease in lateral displacement during an earthquake, thereby reducing the non-structural damage and the possibility of collision between the different buildings. The changes also increase resistance, meaning that structural damage will be caused by more powerful earthquakes than those originally taken into account by the design, reducing the likelihood of structural damage during the structure's useful life, and thus reducing risk.

The surgical block was rehabilitated using shear walls around the building's perimeter. This solution was chosen because it meant that most of the work would be done outside the building, and because it offered the same benefits as are described above in terms of reduction of displacement and of non-structural damage, etc. This restructuring is shown in figure 3.

In the laundry and machine room, the solution retained was to strengthen the existing walls so that they were capable of absorbing and balancing out the loads generated by earthquakes.

Design of the rehabilitation work began in November 1987 and was completed in July 1988. The building work began in May 1989 and has not yet been completed. The building work is due to be completed in December 1991, i.e. after 31 months.

The cost of the rehabilitation is 235 million colones (US$ 2 350 000), 185 million of which were for the initial contract and 50 million for additional work and costs.

This represents an investment of 392 000 colones per bed, and 7.8% of the hospital's value.

During the entire process, the hospital had to reduce the number of beds to a minimum of 400. Unfortunately, a large number of patients were waiting for elective surgery and examination. In the emergency service too, patients frequently had to wait in the corridors until a bed was free. Two patients died while they were waiting for beds. The service's staff was irate and patients became impatient with staff.

Other problems connected the with building work were the constant delays by the construction firm in handing over parts of the work, and the theft of small items such as taps, locks, etc by the building workers.

Hospital staff complained of a lack of central coordination by CCSS's Department of Architecture and Engineering. This was manifest from the very beginning of the work, since the hospital's Director was uninformed of the work that was to be carried out at the hospital, and even less of the programme.

So far, it has not been necessary to purchase services from other hospitals, but merely to reduce the number of admissions, although services will have to be purchased in future. When the surgical block is reinforced, it will be necessary to purchase day surgery services and some elective surgery services.

The staff consider the noise and dust to have been minor problems in this hospital.

3.3 Monseñor Sanabria Hospital

This hospital is located 100 metres from the beach in the port of Puntarenas, and serves as the regional hospital for the central Pacific and Guanacaste areas. It has many specialized services, and its referral hospital is the Mexico Hospital. It caters for a floating population of 500 000.

It comprises a ten-storey main building, a one-storey building housing general services and an outpatient clinic and a three-storey surgical block.

The hospital was designed in 1964, and the medical services were inaugurated in May 1974. It covers a floor area of 17 000 square metres and its value is estimated to be 1 7000 million colones (US$ 15.5 million).

The building was originally built using reinforced concrete frames (beams and columns). The interior walls are made from hollow clay bricks laid on beams and columns that interact with the structure. The external walls are of decorative or solid clay bricks. The building is built on a deposit of saturated sea sand of very limited bearing capacity, and it had to be secured with piles.

Unfortunately, no detailed risk assessment has been carried out to determine the shortcomings of the original structure, nor has there been a study of the liquefaction potential of the sand deposit on which the building stands. Liquefaction is a phenomenon that occurs in saturated sands when ground oscillation causes it to lose its resistance and stability.

The architectural layout of the main building is in the form of a T; the rehabilitation involved building dividing walls at the three extremities of the T (see, fig. 4).*(translator's note: this should be fig.3).*

According to the rehabilitation plans and observations made on-site, the masonry walls will remain as originally planned, in other words their designers do not require them to interact with the main structure. This could jeopardize service in the future on account of damage to the walls.

There is no doubt that the construction of dividing walls improved the structure's behaviour, by reducing lateral displacement and increasing resistance. This will reduce non-structural damage and the risk of a structural failure from an earthquake. The rehabilitation work began in June 1988 and has not yet been completed; i.e. 34 months have been spent on work that was contracted to take 12 months.

The hospital originally had 289 beds, which were reduced to 200 by the rehabilitation work. Surgical cases had to be reduced from 485 to 342 per month and the length of hospital stays was reduced from 5 patient days to 4.3.

The 1991 hospital budget was 1012 million colones (US$ 9.2 million). The cost of the rehabilitation was 127 million colones, 102 million of which correspond to the original contract, and 35 to additional costs and work. This represents 7.5% of the hospital's value, and an investment of 439 000 colones per bed.

The rehabilitation entailed numerous and varied drawbacks for the hospital. Lack of coordination with CCSS's Department of Architecture and Engineering caused such huge problems that no programme was finalized, and the hospital was powerless to compel the building firm to fulfil the contract. The deadline for completion was extended indefinitely and, as happened at the Mexico Hospital, when the work actually began, the hospital administration was unaware of both the kind of work to be done and of programme.

The builders caused huge destruction, and its employees stole the hospital's fittings and installations; the firm refuses to carry out repairs on the grounds that it is not required by the terms of the tender. Apparently, this is a shortcoming in the tender, which is vague about the contractor's obligations regarding the fittings and installations that are to be relocated or rebuilt as part of the rehabilitation. This has been the case at other hospitals that have been rehabilitated. However, the key to ensuring that building firms accept this responsibility is the sincerity of both parties during negotiations, as the tender simply provides a frame of reference.

The hospital administration claims that if it had been informed of the programming, it would have transferred some services to clinics in Puntarenas or hired premises to provide some services. This would have sped up the rehabilitation.

Another problem was that transfers to the Mexico Hospital had to be reduced from May 1989 onwards because its capacity had been reduced by the start of its own rehabilitation work.

One problem caused by the rehabilitation work was that the surgical blocks were closed for 7 months, during which no elective surgery was carried out, with a concomitant loss of earnings.

The hospitals administration complained of the lack of support from the CCSS authorities, and the poor planning and execution of the building work.

3.4 Comparative cost of the rehabilitation

This section provides a cost comparison of the rehabilitation work and other financial data on the hospitals. Table 1 sets out general information, such as the number of beds, (NB), the annual budget for 1991 (AB), the value of the hospital in millions of colones (VH), the total cost of the rehabilitation, including additional costs for readjustments and additional work (VR), and the value of the original contract when the work began (VO).

Table 2, column 2 shows the cost of the rehabilitation in terms of the original number of beds in the hospital; these figures show that the cost ranged from 300 000 to 450 000 colones per bed, with an average cost of 374 000 colones (US$ 3740). In terms of the annual budget, column 3 shows that the rehabilitation cost between 5% and 12% of the annual hospital budget, the average being 8.5%. Column 4 shows that the cost of the rehabilitation ranged from 4% to 7.5% of the value of the hospital.

The figure for the value of the hospital includes the value of the buildings themselves and of the rest of their equipment. Thus, as a percentage of the hospital budget and of its value, the cost of the rehabilitation was relatively low, and it is a worthwhile investment, when compared with the losses caused by the earthquakes.

The figures for the Children's Hospital, in columns 2, 3 and 4, are relatively lower, because its rehabilitation concerned only 61% of the hospital's working area.

The additional costs for readjustment and additional work are shown in column 6; this item increased the cost by up to 69%, with an average of 40%. These figures are not very representative, as the figures for the Children's Hospital substantially modify the figures, since they do not include the cost of changes made to the internal layout at the request of the staff. The cost increase would probably have been 25% if no remodelling had been carried out.

One final piece of comparative data is the percentage reduction in the maximum number of beds available during the remodelling, which fluctuates from 30% to 35 %.

At the Children's Hospital, this figure is fairly unrepresentative since a considerable proportion of the admissions and surgical cases are transferred to the San Juan de Dios Hospital. The figures will subsequently be compared with those for loss and wastage of resources as a result of the earthquakes.

4. THE IMPACT OF THE 1990 EARTHQUAKES ON SOME HOSPITALS

The year 1990 was one of the years of highest seismic activity during the century.

Seismic activity began on 25 March with the Cóbano earthquake, then continued with the Puriscal earthquake swarm between May and July, and concluded with the 22 December earthquake, which was also located in the zone of Puriscal.

These seismic events caused earth movements of moderate to strong intensity at the sites of various hospitals. This section describes the effects of the earthquakes on the reinforced hospitals and on two hospitals which had not been reinforced – the San Juan de Dios Hospital in San José and the San Rafael Hospital in Alajuela.

4.1 The characteristics of the earthquakes

At 7 22 a.m. on Sunday 25 March 1990, an earthquake of magnitude 6.8 on the Richter scale occurred at a depth of 29.7 kilometres, 19 kilometres south-east of Cóbano on the Nicoya peninsula.

The earthquake was caused by the Pacific coast subduction zone. The intensities generated in Costa Rica by the earthquake are shown in figure 4. The Monseñor Sanabria Hospital is located in a zone of intensity VII (MMI), some 40 kilometres from the epicentre.

The earthquake produced maximum accelerations of 0.27g at the base of the Monseñor Sanabria Hospital, 0.17g in Alajuela and 0.10g in San José. The damage caused to the Monseñor Sanabria Hospital will be described later.

The damage caused in the centre of the country may be rated as from light to moderate.

In May, a phenomenon began that was to maintain seismic activity for two months in Puriscal. The phenomenon, known as the Puriscal earthquake swarm, and which is caused by the local intra-plate failure, culminated in the 30 June earthquake. This event of 5.0 magnitude on the Richter scale occurred at a depth of 12 km and generated the intensities shown in figure 5. The hospitals concerned by this study are located in the zone of intensity V (MMI), with the exception of the Monseñor Sanabria Hospital, located in a zone of intensity IV (MMI). The peak ground acceleration in San José was in the region of 0.08g. The damage caused by the earthquake in the metropolitan area was rated from light to moderate.

On 22 December, a further earthquake, of magnitude 5.7 on the Richter scale, occurred; its epicentre was also located in the area of Puriscal at a depth of 25 kilometres.

The intensities produced by this earthquake are shown in figure 6. The damage it caused to buildings and the panic produced among the population led to its being rated as the strongest earthquake experienced in the central part of the country in the last 50 years. Intensities of from VII to VIII (MMI) were observed in the town of

Alajuela, and of VI to VII in San José. The earthquake's epicentre was located 25 kilometres south-west of Alajuela and 32 kilometres south of San José. The earthquake caused considerable damage in Alajuela, Puriscal and in some sectors north and west of San José.

The peak ground accelerations produced by the earthquake were also the highest ever recorded in Costa Rica. In Alajuela, the peak acceleration was 0.45g, and in San José, between 0.13 and 0.2g.

The first two earthquakes mentioned caused no deaths, despite the enormous damage, especially to rural dwellings. Only one person died in Alajuela in the 22 December earthquake. Relatively few people were injured, although many families lost their homes. The number of dead and injured was less than is usually the case in such events in Latin America, probably because all three took place at the week-end, when offices and buildings are usually empty.

4.2 The National Children's Hospital

The highest intensity observed at the hospital was VI, during the 22 December earthquake, after completion of the rehabilitation work.

No damage was caused to the hospital, although some objects fell and cracks appeared in a number of walls. The earthquake produced peak ground accelerations of between 0.15g and 0.2g in San José; these accelerations are slightly lower than those used in designing normal civil engineering works, and approximately half those used for major works. In any case, the ground movement in San José may be classified as from moderate to strong. According to design philosophy, this type of earthquake should cause only non-structural damage and minor repairable damage to buildings. Apparently, the building behaved better than was to be expected according to design philosophy. Although this was not a full-scale test, because the earthquake was less powerful than provided for by the design, the building's behaviour makes it possible to appreciate the benefits of reinforcement, and to infer that the building would behave satisfactorily during more powerful earthquakes.

As regards the behaviour of the staff, the Director and several heads of department said that it was excellent; there was no rush towards the exits, as had been the case during previous earthquakes but on the contrary, the staff stayed at their posts during the tremor. Their behaviour was undoubtedly attributable to their confidence in the strengthened building.

4.3 Mexico Hospital

During the 25 March earthquake, this hospital was affected by an earth movement of intensity VI (MMI). The peak earth movement was estimated to be in the region of 0.10g. At the time, work was still in progress on the last floor of the south-east building, while rehabilitation of the other buildings had not yet begun.

According to the risk assessment study carried out at the University of Costa Rica, the peak acceleration of 0.10g was the acceleration at which structural damage would begin; in other words, structural damage was expected to occur at a peak acceleration of more than 0.10g, below which no damage was expected.

The earthquake had the following impact on the building: no damage was caused to the south-east building, ceilings collapsed and walls were cracked in the central building and surgical block, in the north-west building window panes broke, ceilings collapsed, walls were cracked and a number of columns on the fifth floor started to break. According to the risk assessment study, these columns would be the first to fail.

There was no damage to the laundry.

This earthquake was an acid test for the rehabilitation, because the peak acceleration was approximately one third of that adopted in designing the reinforcements; nevertheless, it certainly revealed the shortcomings of the original structure, to which the risk assessment had drawn attention.

The 30 June earthquake was less powerful than that of 25 March. By the latter date, rehabilitation of the south-east building was complete, and work was under way on the first two floors of the north-west building. Throughout the building, the damage caused by the earthquake was insignificant. An inspection was made of the columns that had begun to fail on the fifth floor, but their condition was unchanged.

The tremor caused by the 22 December earthquake was certainly the most powerful. One district of San José in which an intensity of VII was observed is less than one kilometre from the hospital. According to my own study of the correlation between the damage and the peak accelerations, the hospital experienced peak accelerations similar to those observed in the centre of San José, i.e. between 0.13g and 0.17g.

From the damage observed, it would appear that the movement at the site of the hospital was principally in a south-east-north-west direction. This matches the pattern of radiation of the seismic waves, and may explain why the damage to the parts that had not been reinforced was no greater.

At the time, the state of progress of the rehabilitation was as follows: work on the south-east building had been completed and it was occupied by the hospital; no work had been carried out on the central building, the surgical block or the laundry building. Work was under way on the main façade of the north-west building on floor N6 and on the rear façade up to floor N5; the walls of the emergency stairs had been tied to the structure up to floor N5, and the masonry walls had already been untied from the structure and properly secured against overturning up to this floor.

The damage caused by the earthquake may be summarized as follows: no damage at all was caused to the south-east building; ceilings collapsed, windows were broken and walls cracked in the central building and surgical block; in the north-west building, both structural and non-structural damage was caused. The intensive care unit was on floor N7. In view of the state of progress of the rehabilitation, this floor was a weak link, located on a more rigid structure and subject to the whiplash effect that affects the upper floors. As a result, all the windows in the intensive care unit broke, and the ceiling collapsed. The unit had to be transferred immediately to the already reinforced south-east building. Three cracked columns on floor N/ showed where the failure began. The columns were still attached to the walls, forming short columns, and the walls restricting them in a north-west – south east direction presented cracks up to 5 mm wide.

On floor N6, one column was still confined by walls and its cladding collapsed (the concrete between the edge of the element and the steel reinforcement) On the same floor, one untied wall had not been secured against overturning and as a result its base was damaged.

There was no damage at all in the laundry building; the damage was no greater in the parts which had not been reinforced apparently because the preferred direction of the movement coincided with the direction in which the buildings were most resistant. It should also be borne in mind that an isolated earthquake is but an additional statistical occurrence, and that a particular structure's response to a specific earthquake may differ from its response to another whose peak acceleration is the same, but with different dynamic features.

There was no damage to the electrical and mechanical systems, or to medical equipment.

The staff reacted to the earthquake by running to seek refuge in the parts which had already been reinforced.

It is impossible to estimate the cost of the damage caused by the earthquakes, because the repairs were either included in the rehabilitation or in the hospital's budget as regular maintenance costs.

Nor did this earthquake subject the rehabilitation to a conclusive test, although it once again demonstrated the benefits of rehabilitation for the hospital and the shortcomings of the original structure. It also partly tested the design criterion adopted in calculating the rehabilitation. The criterion was that the building had to be capable of offering elastic resistance (without structural damage) to earthquakes with peak accelerations of 0.18g and less and of offering inelastic resistance (with repairable structural damage but without collapse) to earthquakes of up to 0.30 peak acceleration. The first part of this criterion was put to the test by this earthquake.

4.4 Monseñor Sanabria Hospital

The 25 March earthquake was responsible for the damage caused to this hospital. Those which occurred on 30 June and 22 December caused no damage whatsoever. On 25 March, the state of the rehabilitation work was as follows: the reinforcement walls in the west wing had been built up to the tenth floor, those in the east wing had been built up to the second floor, and those in the north wing up to the sixth floor (see, figure 3).

This situation was undoubtedly responsible for considerable problems of torsion and non-uniform movement in the building, on account of the asymmetrical nature of the extra structural work at the time.

Peak acceleration registered at the base of the building during this earthquake was 0.27g (University of Costa Rica, Seismic Engineering Laboratory). This is below the acceleration suggested by the seismic code for the design of major works.

The damage caused by the earthquake was concentrated in the masonry walls and in the pharmacy, as a result of falling drugs and equipment. No damage was found in the main structure.

The damage to the masonry walls was a result of the failure to untie them from the main structure during the rehabilitation and of the considerable movement that affected this wing because of the torsion resulting from the asymmetrical nature of the reinforcement at the time.

In the view of some specialists, and of the author, the rehabilitation saved the building; however, it needs to be repeated that failure to untie the walls from the main structure and to carry out the rehabilitation in a uniform manner was one cause of the damage.

The National Insurance Institute estimated the cost of the damage caused by the earthquake to be 30 million colones; however, the hospital management considers that it is impossible to make an assessment because repair work was paid for out of the hospital budget and the building firm negotiated other repairs with CCSS's Department of Architecture.

Other losses are attributable to the waste of resources that affected the hospital in the months after the earthquake. As a result of the damage to the brickwork on the upper floors, only 20 of the 200 beds available before the earthquake remained in use. The hospital had to be moved and only the first floor was operational. A few days after the earthquake, the number of beds was increased to 93, and this figure was maintained until September 1990. In other words, the hospital was operating at 32% of its total original capacity, and its monthly budget at the time was 66 295 000 colones. If we consider that 68% of this monthly budget was wasted on account of the reduction in capacity, this means that in 5 months a total of 225 million colones was wasted, i.e. almost twice the cost of the rehabilitation. The actual cost of the wastage was even higher, as it took almost a year to bring the full complement of beds back into use. If the waste of resources during these five months is calculated in terms of the original number of beds available in the hospital, then 778 thousand colones were wasted per bed, a far higher figure than was spent on rehabilitation (see, table 2).

The cost of the repairs and the incalculable loss deriving from the inability to provide medical services should be added to this figure.

The earthquake certainly put the rehabilitation to the test, but it also revealed the considerable operating difficulties caused by damage to the walls.