The problems caused by leaving the walls as an integral part of the structure is not being addressed in this hospital, and in future a similar problem may arise, with the consequent operating difficulties.

According to the CCSS and hospital authorities, the hospital had shifted slightly from the vertical plane, a phenomenon that is perhaps attributable to the low bearing capacity of the sea sand.

### 4.5 San Juan de Dios hospital

This is one of the oldest hospitals in the country; it has nine separate buildings which were built during different periods and with a different number of floors. The tallest building is the five storey medical block. The hospital has a total floor area of 55 000$m^2$.

The hospital has 920 beds and its annual budget is 4 004 million colones (US$ 36.4 million). The hospital benefited from the first antiseismic hospital design in Costa Rica. In 1925, as a result of the damage caused to part of the hospital by the 1924 earthquake, H. T. Purdey, a New York City engineer was given a contract to draw up an earthquake-resistant design. His design for the sector of the hospital concerned was for a two-storey metal-frame block, with a wooden mezzanine and lightweight metal walls (sheet metal with plaster). Over the years, the building has shown its earthquake-resistant qualities.

The hospital is located in the town centre, and the buildings date from 1898, 1940, 1967 and the most recent one from 1990.

The 1990 earthquakes caused little damage to this hospital. However, the 22 December earthquake had a greater impact on it.

During this earthquake, many ceilings collapsed, a few windows broke, the lift jammed and was out of order for two weeks and gaps appeared in the dividing walls between the buildings, causing anxiety among staff. Numerous cracks appeared in the neonatal unit, which had to be evacuated. There was no other damage to equipment because the disaster committee had taken the necessary preventive measures.

According to the personnel manager, the staff responded properly to the earthquake; however, staff were afraid to work in some parts of the hospital which were thought to be dangerous. The hospital staff has requested CCSS completely to evacuate the hospital, although this has so far not been done. The staff agree that the building should be strengthened, even if this means worse working conditions for a time, in order to increase its earthquake-resistant capacity. Their willingness has been influenced by the experience and results of the reinforcement work in other hospitals.

The earthquake caused no major financial loss, and the cost of the repairs was covered by the maintenance budget. It has been estimated at approximately one million colones.

The hospital has not been reinforced, nor has a risk assessment study been carried out to assess its safety. It was capable of withstanding a magnitude VI earthquake with relatively little damage, although it is doubtful that it would be able to withstand earthquakes of greater intensity.

## 4.6 San Rafael Hospital

This hospital is located in Alajuela, and most of its buildings, dating from 1884, count among the oldest hospital buildings in Costa Rica. The most recent buildings at the hospital date from 1970.

Until the 22 December earthquake, it had 218 beds and a useable area of 10 000 $m^2$.

The hospital's annual budget amounts to 783 million colones. The 22 December earthquake reached magnitude VII (MMI) in Alajuela, with peak ground accelerations of 0.45g. These are twice or three times the accelerations registered during the 25 March earthquake.

The 22 December earthquake caused extensive damage to the hospital and reduced its capacity to 85 beds. The oldest building, an unreinforced two-storey brick building was not the most heavily damaged. Plaster was severely cracked and the ceiling in the women's' medical unit fell. A wall in the equipment centre was damaged and had to be demolished.

The most consequential damage to the hospital was the widespread damage to the roof slab and to the crown beams (the upper beams in the wall) of the machine house and laundry. This put the boiler out of commission, and as a result there was no hot water, steam or laundry service. Three months after the earthquake, the situation was unchanged because the Office of the Comptroller-General requires specific procedure to be followed for financial reimbursements and expenditure, even in an emergency, and CCSS had not been able to comply with them. In any case, the time had to be spent on designing the repairs and contracting the work out to a building firm.

As has already been mentioned, the earthquake was responsible for a 65% reduction in the hospital's capacity, causing resources to be wasted in the months following the earthquake. The wastage may be estimated as follows: the annual budget is 65.25 million colones, 65% of which were wasted, in other words a surplus of 42.4 million colones is spent each month on fixed costs, given the diminished capacity. Considering that it will take three months to restore the hospital to normal operating conditions, in addition to the three months during which it has already been operating at a reduced capacity, it will have been virtually inactive for six months, and a total of 254.4 million colones will have been wasted.

This is a far greater sum than was spent on the rehabilitation of the Mexico hospital. It also represents a wastage of 1 167 000 colones per bed. From this angle, the rehabilitation described in the previous chapter seems a worthwhile investment.

Although in financial terms the amounts lost and invested are similar, the incalculable amount lost as a result of the unavailability of medical services and the subsequent investment in repairs should also be taken into account.

Approximately 20 million colones will have to be invested in repairs in the San Rafael hospital.

The earthquake also caused other problems in addition to those already described; in the immediate aftermath of the earthquake, staff refused to work and surgical operations were put on hold, admissions were reduced and rapid discharge of patients encouraged, while space had to be found to transfer patients to other hospitals because the capacity of the Mexico hospital was reduced by rehabilitation work.

This latter hospital admitted 200 patients after the 22 December earthquake, 8 of whom had to be transferred to hospitals in San José.

There was wholesale chaos throughout almost the whole hospital system in January 1991 on account of the heavy demand for admission to hospital and the low capacity available on account of the damage to the San Rafael hospital and the reduced capacity of the Mexico and Monseñor Sanabria hospitals because of rehabilitation work.

## 5. ASSESSMENT OF THE HOSPITAL REINFORCEMENT PROGRAMME

### 5.1 Effectiveness of the structural reinforcements

Only two of the five hospitals studied were subjected to significant earth movement.

One of them was the Monseñor Sanabria hospital, which was affected by peak ground accelerations of 0.27g and which was located in an area where the intensity of the 25 March earthquake reached VII (MMI). At the time, the hospital had been partly reinforced.

The other was the San Rafael hospital, which was subjected to accelerations of up to 0.45 g during the 22 December earthquake. This hospital is located in an area in which magnitudes between VII and VIII (MMI) were recorded. The rehabilitation of the Monseñor Sanabria hospital is thought to have saved the building, and if the building work had been carried out more symmetrically, there would probably have been less non-structural damage. In the case of the San Rafael hospital, if the laundry had been designed in accordance with earthquake resistant norms or if it had been reinforced to avoid the excessive damage to the roof, the operational problems that had to be addressed in the months following the earthquake would have been avoided. It was in these two cases that wastage of resources on account of operational problems, which could have been avoided or lessened with a minimum of preventive measures, was greatest.

The three other hospitals in San José experienced magnitudes of VI (MMI) during the 22 December earthquake. If the response of the reinforced buildings or parts of buildings is compared with that of the unreinforced parts, it is clear that the non-

structural damage that occurred in the unreinforced parts San Juan de Dios Hospital and some buildings at the Mexico Hospital) was considerably greater than in the reinforced hospitals (Children's Hospital and some buildings at the Mexico Hospital), where there was no such damage. From the structural angle, the reinforced parts behaved admirably, unlike the unreinforced parts which, although subjected to an earthquake whose magnitude was below that for which they were designed, showed signs of weakness that would threaten the structures during more powerful earthquakes.

We may conclude that the structural reinforcements carried out to the hospitals were an asset during the 1990 earthquakes.

## 5.2 Cost effectiveness of the investment in reinforcement

Analysis of the cost effectiveness of this type of investment should not be limited to cost analysis; it should also include the benefit for society of continued medical services after a disaster. It is hard to assess these benefits, which depend on the type of hospital facility concerned and the circumstances of each society.

From the purely financial angle, we may conclude, on the basis of the information provided in the previous chapter, that the investment has been worthwhile since it averts a waste of resources. Total losses at the Monseñor Sanabria hospital have been estimated at 255 million colones (wasted resources plus direct losses); this represents a total loss of 882 000 colones per bed. At the San Rafael hospital, total losses amounted to 265 million colones, representing 1 260 000 colones per bed. This means that average losses attributable to the earthquake amounted to 1 071 000 colones per bed. If we use this average figure to calculate the potential losses at the Mexico hospital and at the Children's hospital after a powerful earthquake and in the absence of reinforcement, we obtain the figure of 642 million colones at the Mexico hospital and 401 million at the Children's hospital. This is far greater than the investment in rehabilitation.

We have retained the figures for losses at the Monseñor Sanabria hospital, despite the fact that it is one of the hospitals which have been reinforced, because the asymmetrical and incomplete nature of the rehabilitation at the time of the earthquake was responsible for a large part of the non-structural damage. The rehabilitation work preserved the building's structural integrity.

## 5.3 Problems encountered during the building work

The difficulties that arose during the building work have already been described; we shall summarize some of the most significant ones here.

At the institutional level, there was a lack of coordination between the different departments involved. A number of officials in the Department of Architecture and Engineering considered the projects as simply additional building projects. There was no coordination with Medical Administration, which is responsible for running the service affected by the rehabilitation work. Nor was there any coordination between this department and the different hospital managements. The hospital authorities

should have insisted on this coordination and on programming the work, before it started. This apparent weakness on the part of the hospital directors contributed to the subsequent confusion. The directors complained of the lack of support from their superiors.

Another problem that frequently occurred was the building firms' failure to meet the partial deadlines. Three clearly identifiable factors were responsible for this: the nature of the rehabilitation work itself, involving countless unforeseen jobs, the lack of coordination with the hospital authorities to clear work areas, and the delays in negotiations over and failure by CCSS to pay for the extra work. This latter problem arose on account of the ambiguity of the calls for tender, which failed to specify which work would be considered additional and which was part of the contract. For example, some companies wanted to charge for repairs to a floor which had to be removed to be replaced by a ground plate.

Another reason for this situation was that no architectural plans showing the changes or the effects of the rehabilitation on the finishing of the buildings, and the bids were based solely on structural plans.

### 5.4 Possibility of reinforcing the rest of the hospital system

The possibilities for extending this programme to the other hospitals in Costa Rica are quite promising, although this would pose financial problems. At present, Costa Rica is facing one of the greatest fiscal deficits in its history, and both the Government and governmental agencies are doing everything possible to cut back on public expenditure.

At the moment, financial problems are alone responsible for the delays in this programme. The reinforcements carried out by CCSS inspire sufficient confidence. Moreover, the 1990 earthquakes have heightened awareness of the need to evaluate structures and to strengthen them when appropriate. It should be borne in mind that the 1987 decree requiring all national institutions to carry out risk-assessment studies and to reinforce all their buildings if necessary is still in force, a fact of which the CCSS authorities are aware.

In the view of the CCSS Operations Management department, the priority in the reinforced hospitals should be given to maintenance and damage prevention for non-structural elements and equipment. It also believes that an evaluation plan is required to allow decisions to be taken in the event of powerful earthquakes.

From the technical angle, Costa Rican consulting and building firms have acquired sufficient experience of this type of work. The CCSS architecture and engineering department and the other departments concerned have acquired valuable experience which they can apply to similar projects. The knowledge and experience as a whole will benefit new projects, and the procedure will certainly improve.

### 5.5 The likely situation in the aftermath of an earthquake in San José

If an earthquake of the magnitude of the Alajuela earthquake (i.e. of magnitude VII to VIII (MMI) were to occur in San José, the number of injured would in all likelihood be over one thousand. The number of beds available in San José is 3000, 2000 of which would still be available – enough to cater for the demand that would arise. The figure of 2000 has been calculated on the assumption that half the beds in unreinforced hospitals would be lost, and that no beds would be lost in the reinforced hospital.

The assumption that no beds would be lost in the reinforced hospitals is supported by the way the hospitals responded to the 1990 earthquakes, and which would seem to confirm that the reinforcements were appropriate.

Some non-structural damage may occur in these hospitals, causing some disturbance to their activity, although this would be easily resolved thanks to the emergency plan.

The assumption that 50% of the beds would be lost in the unreinforced hospitals is simply an optimistic one. It should be borne in mind that in October 1986 in San Salvador, 57% of the installed capacity was destroyed, on 3 July 1983, 100% of the capacity was destroyed in San Isidro, and 65% and 68% in Alajuela and Puntarenas respectively. This 50% loss amounts to approximately 1000 beds, and if we apply the yardstick adopted in section 5.2 for financial losses, the figure is in excess of one thousand million colones. This likelihood makes it essential to pursue the hospital evaluation and reinforcement plan.

## 6. RECOMMENDATIONS

We set out below a number of recommendations for putting this hospital reinforcement programme into practice in other countries, drawing on Costa Rica's experience, to avert the problems that arose in there.

### 6.1 The first steps

It is no easy task to persuade those responsible for the political and financial decisions to take stock of the situation. The starting point for this task is to convince the groups of professionals responsible for hospital design, building and operation, so that each of them will be able to provide their input, and will not oppose the changes to be made.

At this stage, an evaluation of one or more hospitals would be valuable. Concrete data are required, and these could be provided by academics or research agencies.

The first evaluation to be made needs to be concise, and clearly to describe the risks to which hospitals are exposed. Comparisons could be made with the impact of other earthquakes, and projections made for the likely losses in the event of a destructive event at the site of the hospital.

It will not be possible to determine the cost of rehabilitation until a detailed design has been prepared. The costs will depend on the hospital's original state, the solution

adopted for the rehabilitation and construction costs in each country concerned. The data in this report will be of use in this connection.

In many cases, the figures will be in the millions, although in every case they will amount to no more than a small percentage of a hospital's annual budget. As regards the building work, it will always be cheaper to and quicker to carry out the rehabilitation work with the hospital housed elsewhere; if this is not possible for operational or financial reasons, the work should be done in stages which could be spread over several years, thus lightening the financial burden.

## 6.2 Structural design and inspection

The structural design for a hospital rehabilitation project is more complicated than a regular engineering project, and must be carried out by specialists in earthquake-resistant engineering. The design needs to be architecturally feasible, to provide sufficient resistance and rigidity to guarantee stability during earthquakes and make maximum use of the existing structure, for reasons of economic feasibility. As regards resistance and rigidity, the structure of a hospital must behave elastically (without structural damage) in response to powerful earthquakes of a magnitude that is likely to occur during its useful life. Ordinary structures would suffer considerable damage as a result of such events. It would also need to behave inelastically (with structural damage but without collapse) in the event of earthquakes of a magnitude of which there is little likelihood during its useful life. Such earthquakes would have disastrous consequences for ordinary buildings.

The structural design and the method used are fundamentally important; no less important is rigorous inspection of the construction work. Sound and thorough construction design is of no use if the work is badly carried out. There is a high likelihood of constructional errors being made, hence the need for rigorous and conscientious inspection; this is what determines the success of the proposed rehabilitation and justifies the sacrifice it requires.

## 6.3 The call for tenders

This stage in the contractual process is an element that will help and assist in the subsequent building work and in any negotiations that take place.

The call for tenders must require the contractor to provide a programme of work, for the approval of the hospital authorities. Ideally, the programme should be jointly determined by the hospital and the construction firm. It should clearly specify the fines to which the company shall be liable in case of partial or total failure to complete.

It should also specify the compensation to which the hospital shall be entitled in case of failure to complete and the procedure to be followed for negotiating extensions of deadlines and changes to the programme of work.

To determine responsibility for the work's existing finishings, plans will be drawn up indicating the changes to be made to them, the effect on them and their appearance on completion of the construction work

The call for tenders should also define what constitutes additional work, and the procedure to be followed in negotiating its cost.

The extent of the building firms' responsibilities towards external works such as gardens, means of access, pavements, etc., should be defined. It should also be determined how the company and the hospital will avert damage to property. The call for tenders should also lay down the rights and obligations of the hospital authorities towards the construction, as it is they who shall permanently collaborate with the building firm and evaluate its work.

### 6.4 Safety of equipment and of non-structural elements

These items can also suffer considerable damage which may seriously jeopardize the provision of services after an earthquake. This damage may occur even if the building is undamaged.

A number of relatively simple procedures make it possible to ensure the safety of these systems.

- Secure elements that might fall over or slide about;
- Limit the movement of light fittings, ceilings, tubes, etc;
- Equip pipes with flexible joints at locations where there are joints in the building or where significant movement occurs;
- Fit shelves with barriers to prevent receptacles from falling;
- Locate electric junction boxes away from pipes or receptacles carrying or containing liquids or gases;
- Place adhesive strips or plastic on the window panes of the major services.

Many other such measures could be identified and adopted after a review of the state of each item of equipment or system.

## 7 CONCLUSIONS

- This report has shown that earthquakes cause all kinds of damage to hospitals. In turn, structural and non-structural damage cause operational problems, financial loss and wastage of resources.
- The most significant damage to Costa Rica's hospital system as a result of the 1990 earthquake was the loss of services and wastage of resources.
- These losses were twice or three times as high as the amount spent on the rehabilitation.
- The completed rehabilitation work preserved the buildings' structural integrity, and in two or three instances significantly diminished non-structural damage. The rehabilitation has proved its effectiveness.
- The cost-effectiveness of the rehabilitation is apparent if we compare it with the financial losses that occurred in 1990 and with the potential financial

losses from even more powerful earthquakes. The work appears even more cost-effective if we bear in mind the possibility of preserving services during a seismic emergency.

- As a result of the rehabilitation, staff in the reinforced hospitals were less apprehensive about earthquakes.
- The building processes could have been improved by systematic planning, by incorporating into the calls for tenders the clauses required to avoid ambiguity and by ensuring coordination of the process among all the sectors concerned.

The material for this report is based on interviews, visits, examination of plans and other tender documents, bibliographic research and other written documents; it has been drawn up at the request of the Natural Disasters Department of the Pan American Sanitary Bureau's Office in Costa Rica. The report was written in February and March 1991.

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**TABLE 1**
**General information on hospitals**

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| Hospital | Total n° of beds (NB) | Annual budget in colones (AB) | Value of hospital (VH) | Value of rehabilitation (VR) | Value of original contract (VO) |
| Mexico | 600 | 3 000 000 | 3000 | 235 000 000 | 185 000 000 |
| Children's | 375 | 2 100 000 | 2600 | 110 000 000 | 65 000 000 |
| Mons. Sanabria | 289 | 1 012 000 | 1700 | 127 000 000 | 102 000 000 |

**TABLE 2**
**Relative cost of rehabilitation**

| (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|
| Hospital | VR/NB (thousands of colones/bed) | VR/AB | VR/VH | VO/VH | VR/VO |
| Mexico | 392 | 0.078 | 0.078 | 0.044 | 1.27 |
| Children's | 293 | 0.052 | 0.042 | 0.025 | 1.69 |
| Mons. Sanabria | 439 | 0.125 | 0.075 | 0.06 | 1.34 |
| Average | 374 | 0.085 | 0.065 | 0.043 | 1.40 |

**Table 3**
**Reduction in n° of beds**

| (1) | (2) | (3) | (4) |
|---|---|---|---|
| Hospital | N° of beds (NB) | min. NB during rehabilitation | maximum % reduction |
| Mexico | 600 | 400 | 33.3 |
| Children's | 375 | 30 | 92.0 |
| Mons. Sanabria | 289 | 200 | 30.8 |


Surgical block

General services

C

East wing A West wing B

Overall plan, National Children's Hospital

Structural reinforcement walls, to be built

Structural reinforcement walls, to be built

Existing wall

Architectural plan of the restructured East wing, National Children's Hospital (Scale: 1:400)

Fig. 1
National Children's Hospital

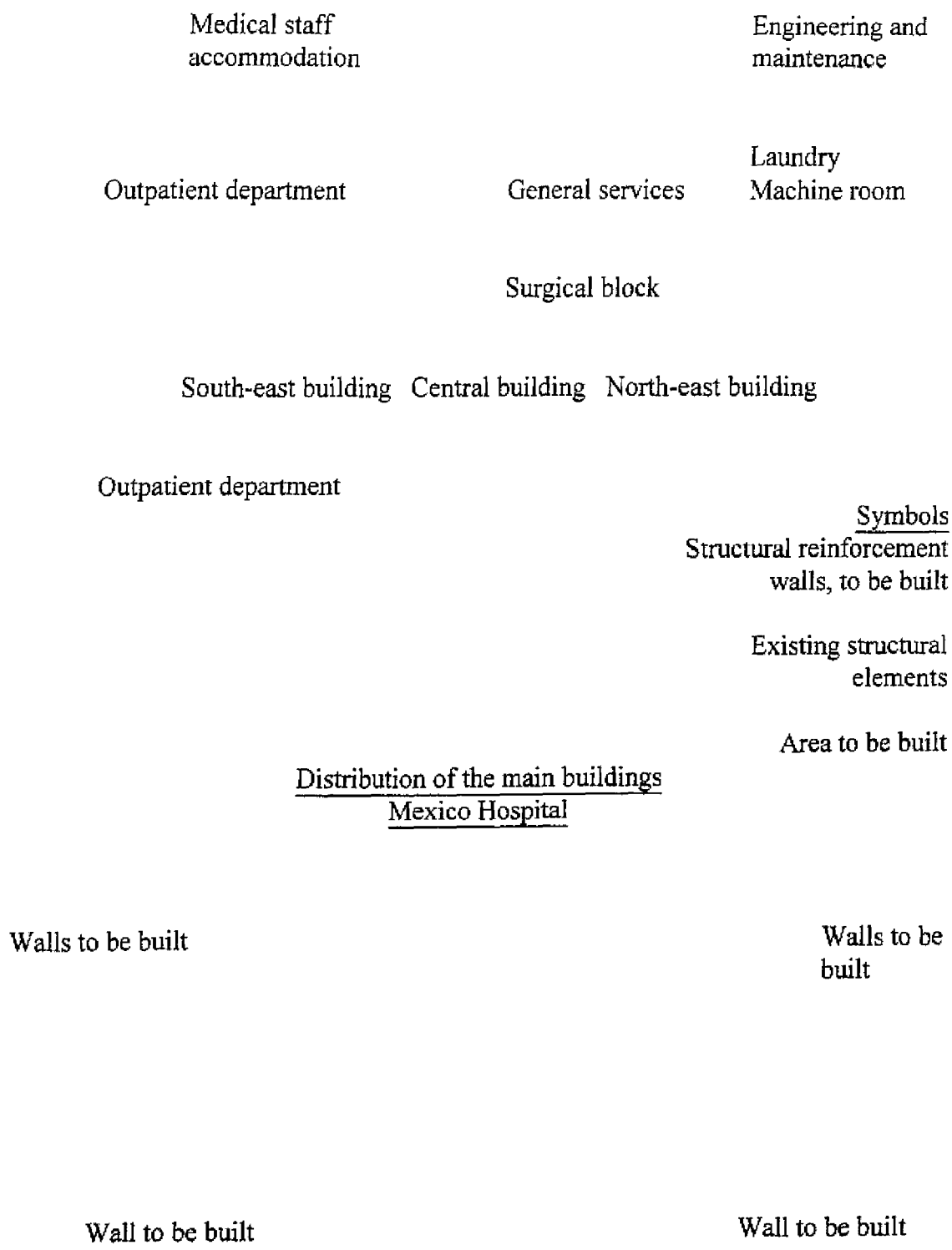


Figure 2, Mexico Hospital

Emergency staircase

Architectural plan of the restructured
North-east building (not to scale)

Symbols
Structural reinforcement walls, to be built

Existing structural elements

Area to be built

Cross section (not to scale)

Figure 2, (continued)
Mexico Hospital


Overall plan (not to scale)
Monseñor Sanabria Hospital

Architectural plan of the
restructured Admissions Building (scale: 1:500)

Figure 3
Monseñor Sanabria Hospital

FIGURE 4

Cobano earthquake of 25 March 1990
Magnitude 6.8 (Richter)
Location of hospitals
1 =Mexico, National Children's, San Juan de Diós
2 =San Rafael (Alajuela)
3 =Monseñor Sanabria

FIGURE 5
Guatuso-Puriscal earthquake of 30 June 1990
Magnitude 5.0 (Richter)
Location of hospitals
1 = Mexico, National Children's, San Juan de Diós
2 = San Rafael (Alajuela)
3 = Monseñor Sanabria

Epicentre

FIGURE 6
Barbacoas-Puriscal earthquake of 22 December 1990
Magnitude 5.7 (Richter)
Location of hospitals
1 = Mexico, National Children's, San Juan de Diós
2 = San Rafael (Alajuela)
3 = Monseñor Sanabria