TABLE 9

Earthquake Response Results
IMSS Reforma Building 1, Column Line 4

(RF2 Ground Motion Record: October 1991)

Building Condition	FORCES: Base Shear (Tons)	Base Shear Coefficient	Force in Critical Column (Tons): Comp.	Ten.	Roof Acceleration (cm/sec^2)
Bare Frame	153	0.08	85	84	110
Frame W/ADAS	172	0.11	316	275	233
Frame W/Elastic Bracing	188	0.12	429	380	357

Building Condition	DEFORMATIONS: Displacement At Roof (cm)	Story Drift (cm): Max.	Ave.	Story Drift Ratio: Max.	Ave.
Bare Frame	39.6	5.0	3.6	0.0125	0.0089
Frame W/ADAS	33.2	3.9	3.0	0.0098	0.0075
Frame W/Elastic Bracing	34.9	4.7	3.1	0.0118	0.0078

Tables 8, 9 and 10 are presented with the purpose of showing the overall earthquake response performance improvements to this building provided by the ADAS retrofit. In addition, the tables also show the benefit of retrofitting the buildings with ADAS devices in lieu of retrofitting with strong bracings or shear walls.

Comparing the roof displacements for the bare frame and frame with ADAS cases for the three column lines reveals that the ADAS retrofit reduces the roof displacements by 15 to 20 percent. Story drift, however, is a more important indicator of potential damage. By comparing story drifts, it can be seen that the frame with ADAS retrofit produces 25 to 40 percent reductions in maximum story drifts. Because damage increases exponentially with story drift, the reduction in potential earthquake damage is even greater than the reduction in story drift. It is important to note that the story drifts for the frame with elastic bracing (strong bracing) are in all cases greater than those for the frame with ADAS. The reduction in story drift between the bare frame and frame with ADAS cases reflects the increased strength, stiffness, and damping for the latter case.

TABLE 10

Earthquake Response Results
IMSS Reforma Building 2, Column Line M

(RF2 Ground Motion Record: November 1991)

	FORCES				
Building Condition	Base Shear (Tons)	Base Shear Coefficient	Force in Critical Column (Tons) Comp.	Ten.	Roof Acceleration (cm/sec^2)
Bare Frame	455	0.11	317	58	178
Frame W/ADAS	652	0.13	477	272	230
Frame W/Elastic Bracing	680	0.14	556	340	340

	DEFORMATIONS				
Building Condition	Displacement At Roof (cm)	Story Drift (cm) Max.	Ave.	Story Drift Ratio Max.	Ave.
Bare Frame	30.9	5.9	3.1	0.0147	0.0077
Frame W/ADAS	25.8	3.5	2.6	0.0088	0.0064
Frame W/Elastic Bracing	32.1	4.5	3.2	0.0113	0.0080

The maximum story drift ratio allowed by the Mexico City Seismic Regulations of 0.012 is compared with the story drifts obtained for the bare frame, frame with ADAS and frame with elastic bracing. Tables 8, 9 and 10 reveal that the bare frame condition exceeds the maximum allowable drift in all three column lines shown, while the frames with ADAS are all well under this limit; even under the drifts of the frame with elastic braces. This is due to the fact that the energy dissipation and damping reduce the seismic force.

However, it is interesting to note that the column axial forces given in Tables 8, 9 and 10 show about 50 percent increase from the bare frame to the frames with ADAS and with elastic bracing. This is a clear effect of the bracing action, which affects only a few columns on the building, while reducing the axial loads in others. Importantly, the column axial loads, both axial compression and tension, are substantially less for the frame with ADAS than they are for the frame with elastic bracing condition.

In comparing the roof acceleration for the bare frame and frame with ADAS conditions, it can be seen that the accelerations increase for all three column lines because of the increased stiffness and strength for the frame with ADAS conditions and higher accelerations for the frame with ADAS, are again less than for the frame with elastic bracing for all three column lines. This means that there will be less acceleration-related damage for the frame with ADAS than there would be for the frame with elastic bracing.

It is important to note that as in the case of the Izazaga #38-40 building, the foundation loads for the ADAS retrofit are about 20 percent less than they would have been if the building had been retrofitted with conventional braced framing.

CONSTRUCTION ISSUES

Retrofitting existing structures while in operation demands serious consideration of the factors involved. In particular, since the installation of both the bracing frames and the ADAS supports engage two adjacent floors at the same time, special precautions are to be taken to guarantee the safety of the construction at the same time as minimizing interference with the building's users and their normal operations. It is possible to minimize such interferences, but never to eliminate them; this perhaps is the greatest objection by the building's owners; they have to face the serious complaints from the building's users.

However, the argument that such repairs are necessary to guarantee the building's safety is always helpful because it demonstrates the owner's concern for the safety of the building occupants.

In many instances, such as in the case of the Izazaga #38-40 building, temporary shoring has to be placed in 2 consecutive floors: the floor in which the bracing is to be installed and the level immediately under it. This shoring is to be localized in these areas which will have to experience local demolition to anchor the fastening elements of the bracings and the ADAS top support.

At the same time, the actual forces imposed by the braces to the adjacent columns and the ductility demand required to allow for the non-linear behavior of the frame with ADAS may require strengthening of the columns. Depending upon the strength and ductility required, such reinforcement will be satisfied by the typical jacketing procedure with four corner steel angles and horizontal ties (Alcocer, 1991). Eventually, an exterior steel circular jacket is needed to supply the strength and ductility requirements. In any case the anchoring detail of the steel jacketing to the existing structure requires special attention. Figures 26 and 27 show typical details of all of the above.

Another serious problem that is common in existing construction regards hidden defects of the construction itself; namely reinforcing column or shear-wall bars of previous retrofits which had not been properly anchored into the existing construction; deficient strength of building materials; unrecorded and undocumented changes and modifications of the as-built structure; altered dimensions of structural members, as compared to those registered in the construction documents; impediments and difficulties to access to the specific locations where the retrofit work is to be done (electrical room, computer facilities, telephone switchboard and the like).

All of these factors and more may alter the strategy planned for the retrofitting work as well as the time schedule, and consequently the estimated cost of the retrofit.

Of prime importance is the availability of previous construction documents of the original structure, which will serve to build up the analytical computer models of the original structure. The lack of such documents necessitates extensive field measurement and inspection, much of which is normally difficult to accomplish because it involves the removal of false ceilings and architectural finishes, not always likely to be dismantled.

In summary, the author wishes to communicate his experiences with the retrofit of the three buildings. The various difficulties encountered in the physical implementation of the steel bracings, column jacketing and installation of ADAS devices on occasion exceeded the expected problems. These retrofit operations definitely demand skilled personnel and quick engineering response to overcome challenging construction conditions.

CONCLUSIONS

The inelastic response of a building can be effectively controlled to improve its stiffness and to minimize the earthquake damage by the proper design and installation of the ADAS devices, as such devices can substantially absorb most of the energy dissipation demands and increase building safety.

The three buildings whose seismic retrofit and/or upgrade was implemented through the use of energy dissipative devices demonstrated a very substantial improvement in earthquake resistant response at reasonable costs. In these particular cases, the retrofit was made while the buildings were in operation, which represented one of the most convenient features of this type of retrofit, as compared to more conventional strengthening schemes, since they involve much less construction activity.

However, it must be emphasized that skilled construction labor is required to adapt the steel structural reinforcements (bracing and jacketings) to existing construction. This activity also demands good engineering judgment and prompt engineering response to a broad variety of construction cases difficult to foresee in the retrofit project.

Even though the additional engineering effort in carrying out the numerous non-linear analysis to design the ADAS devices is very substantial, as compared with conventional structural analyses, the increase in new software and powerful and fast microcomputers will eventually ease it and be essential for a better understanding of the physical phenomena. Likewise, the new research being done at several institutions as well as the observations from the monitoring of instrumented buildings with ADAS will bring new insights and trends to adjust the current technology and engineering practice to a better level of engineering knowledge, commonly known as the state-of-the-art, of the seismic resistant design.

It is therefore recommended that the communication among technicians, researchers, academia and practitioners be increased, towards a better fulfillment of the engineer's role in society.

ACKNOWLEDGMENTS

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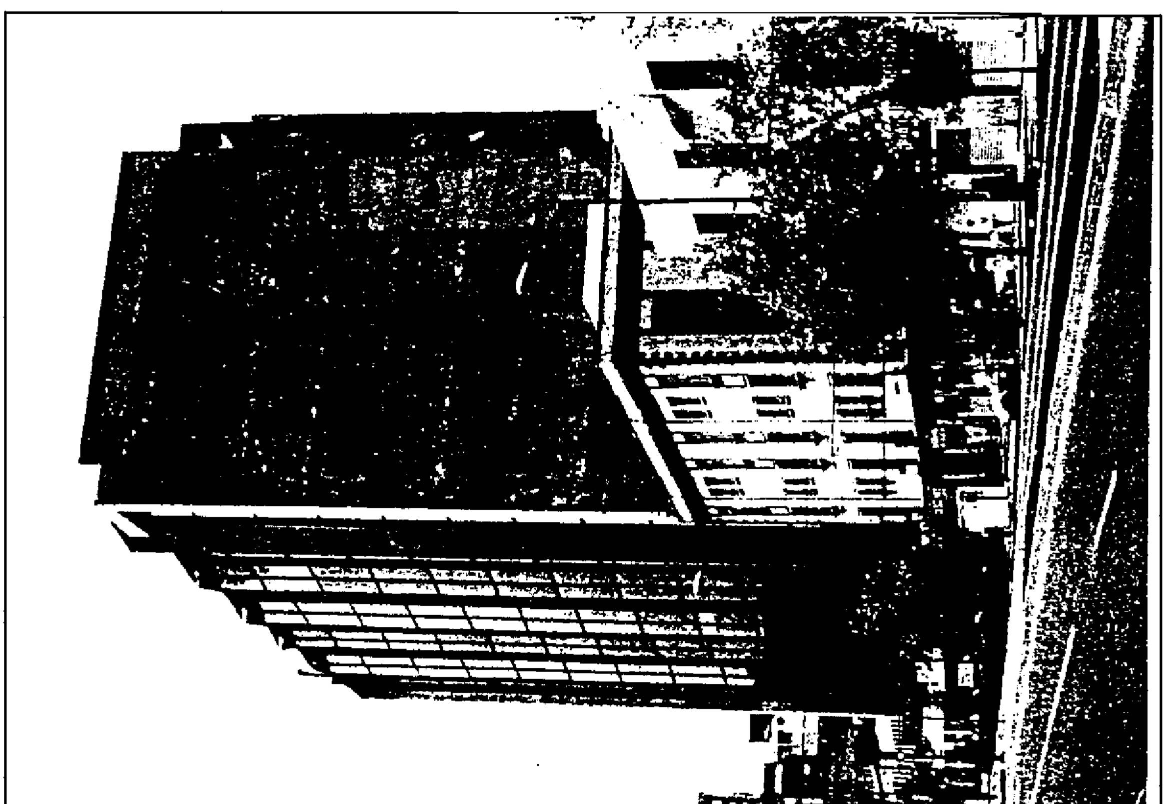


Figure 1 Photo Izazaga #38-40, Front.

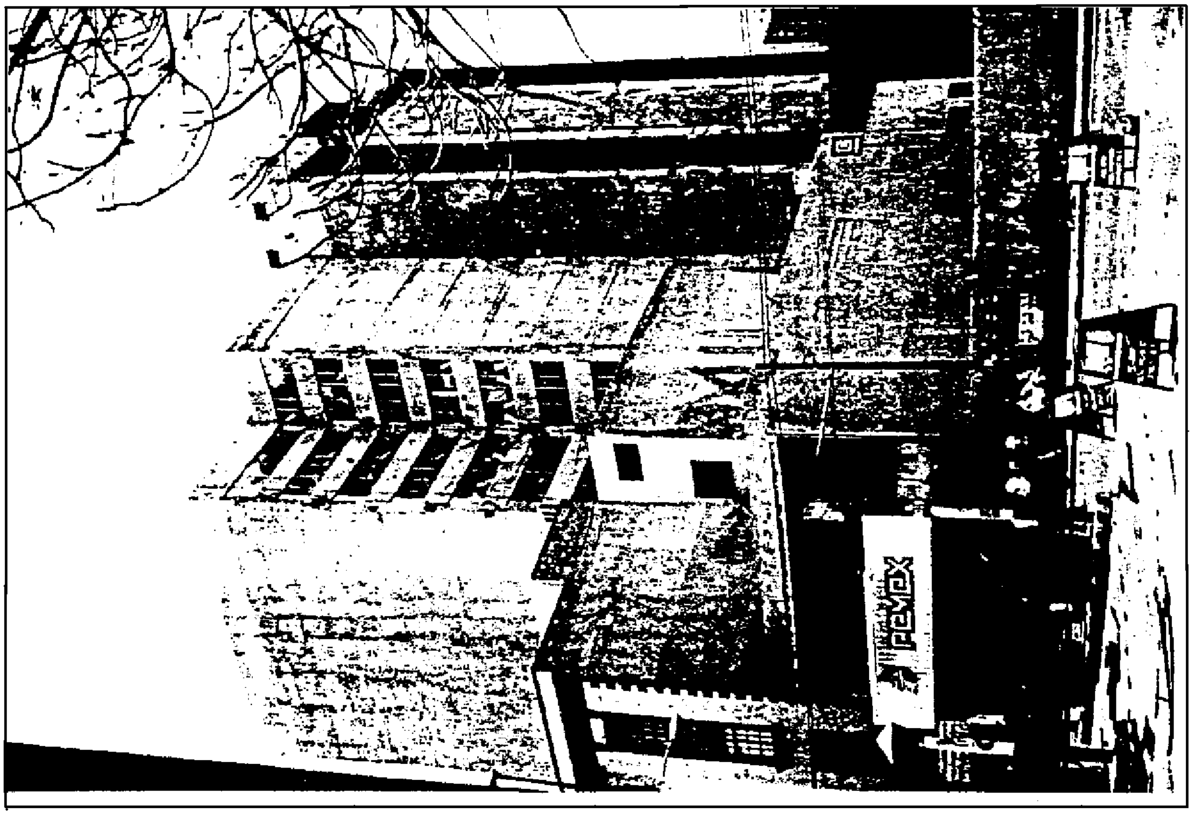


Figure 2 Photo Izazaga #38-40, Back.

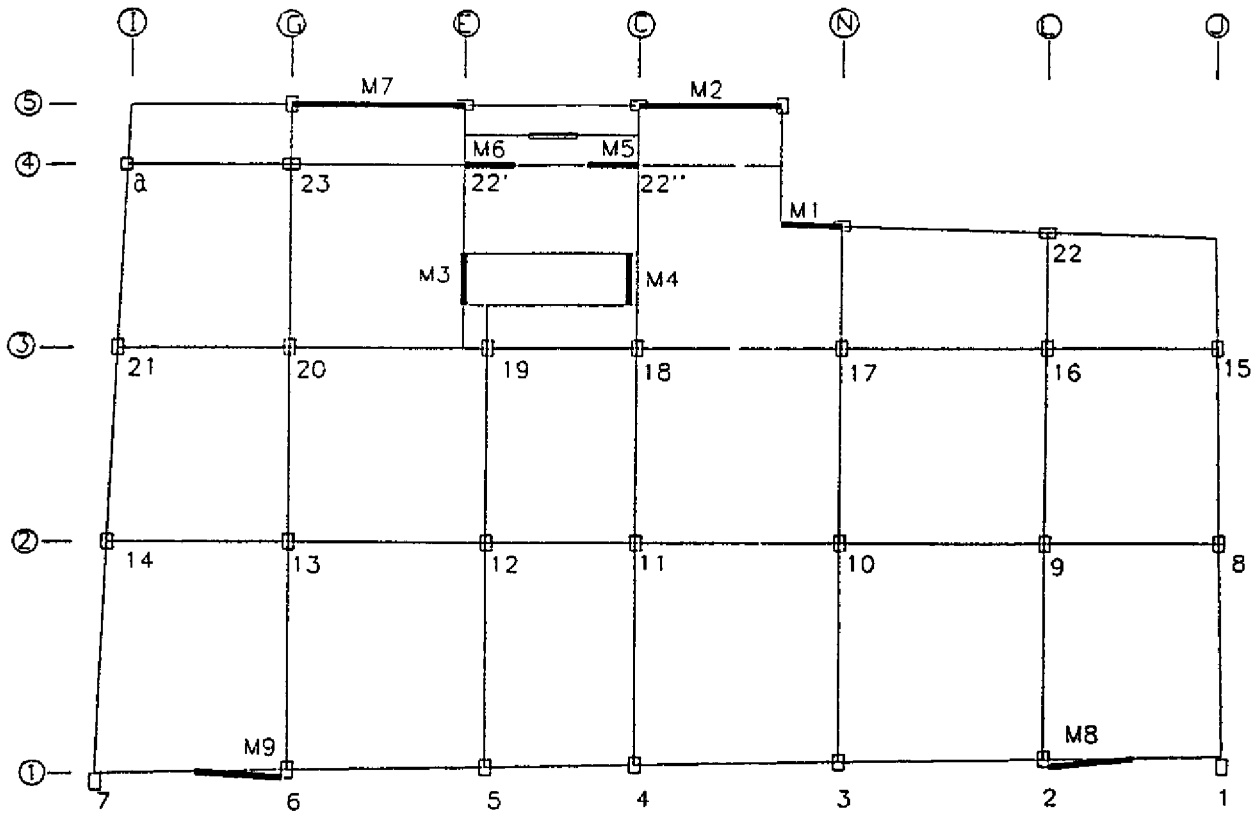
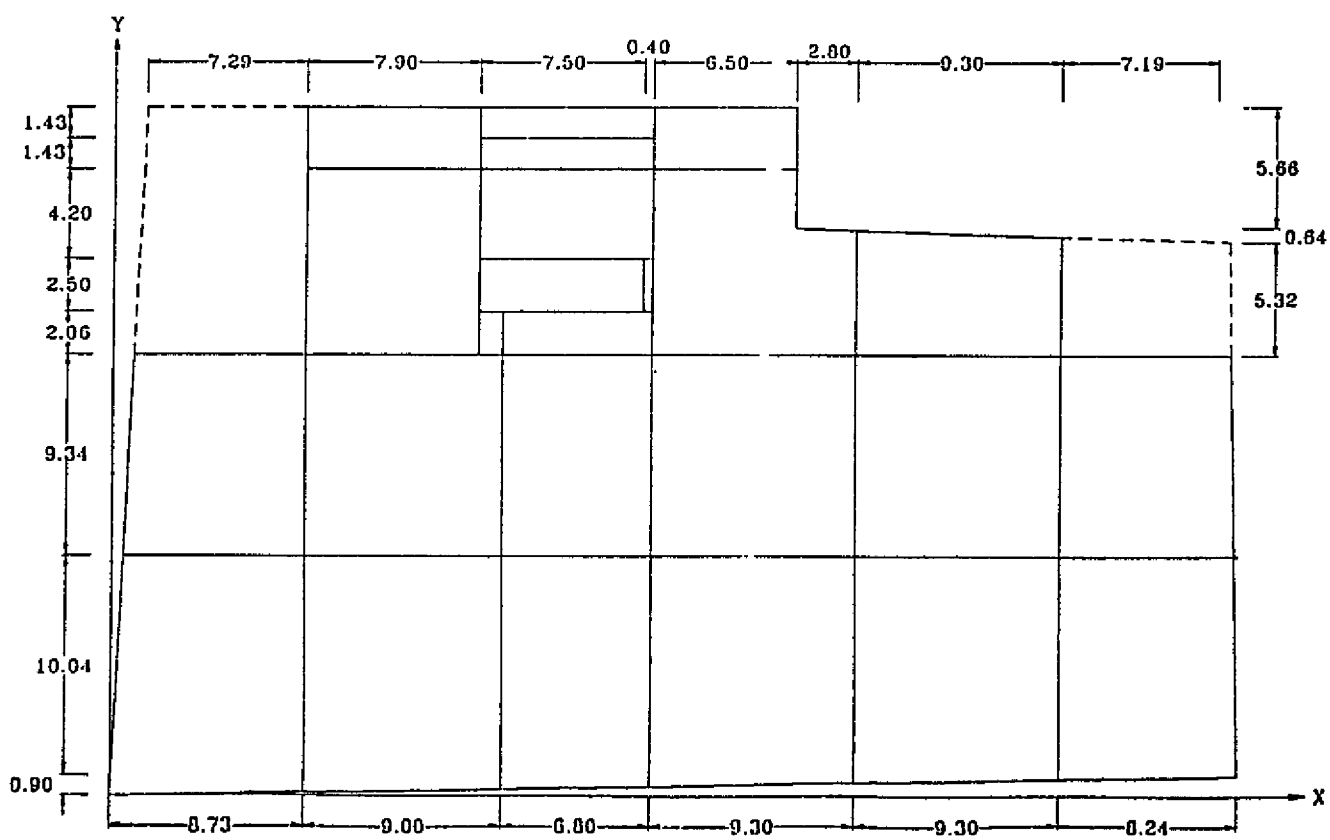


Figure 3 Plan of levels N1 to PB, axis, columns and walls.



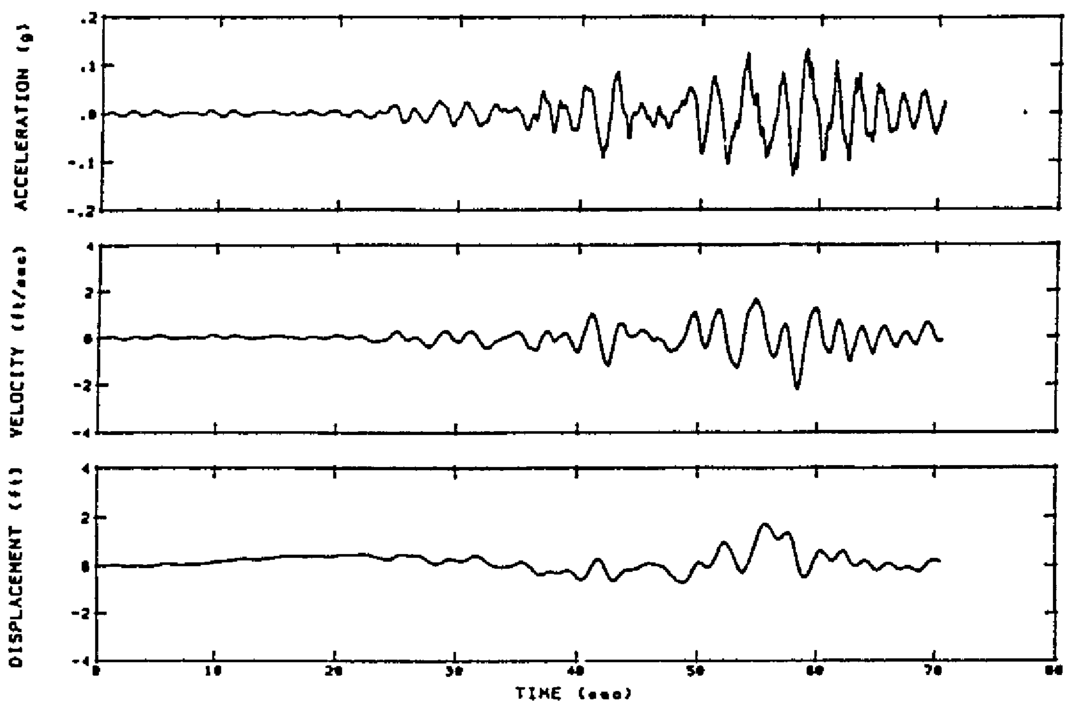


Figure 5A Artificial Acceleration, Velocity and Displacement Time-History Records for Izazaga #38-40 Site (IZA Acceleration Record)

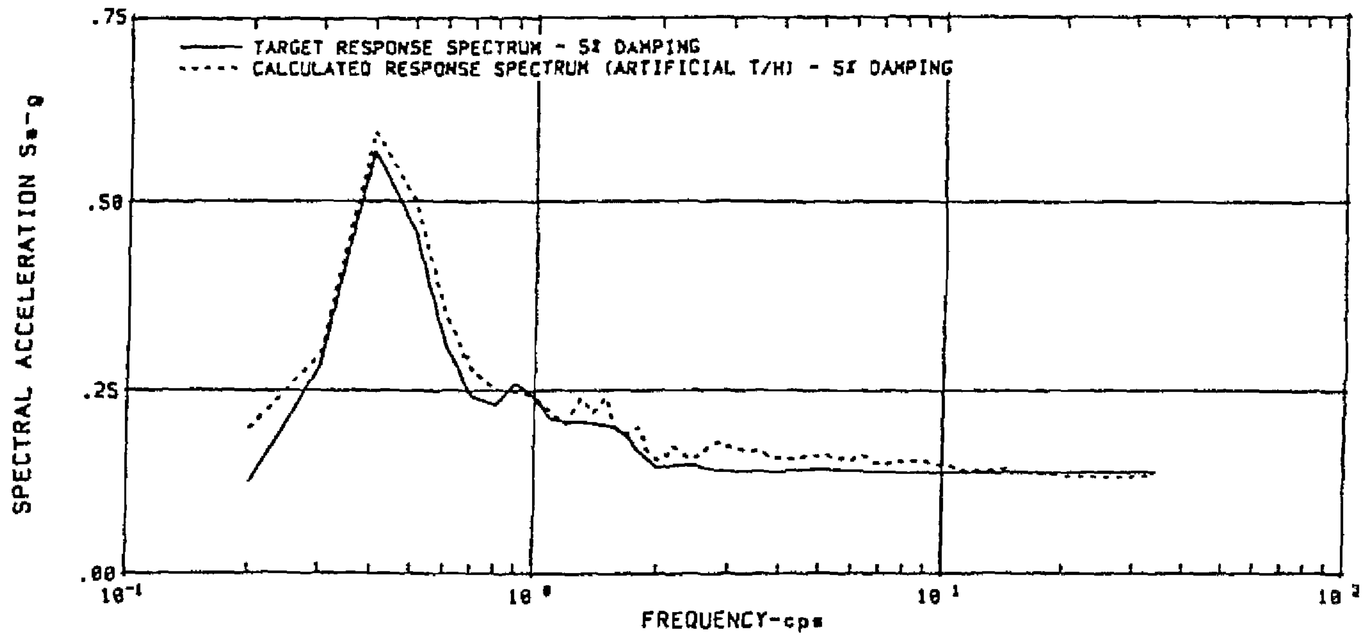


Figure 5B. Target Response Spectrum and Response Spectrum CalculatedUsing the Artificial Record Designated IZA for 5% Damping

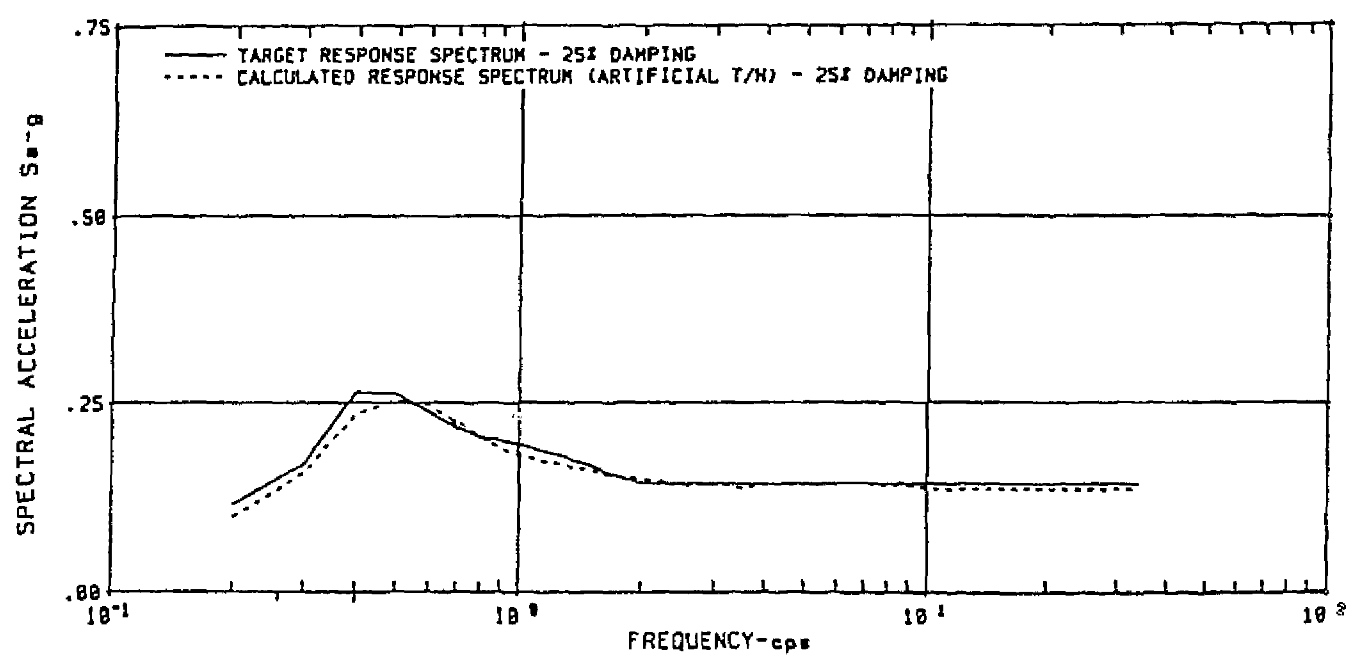


Figure 5C Target Response Spectrum and Response Spectrum Calculated Using the Artificial Record Designated IZA for 25% Damping

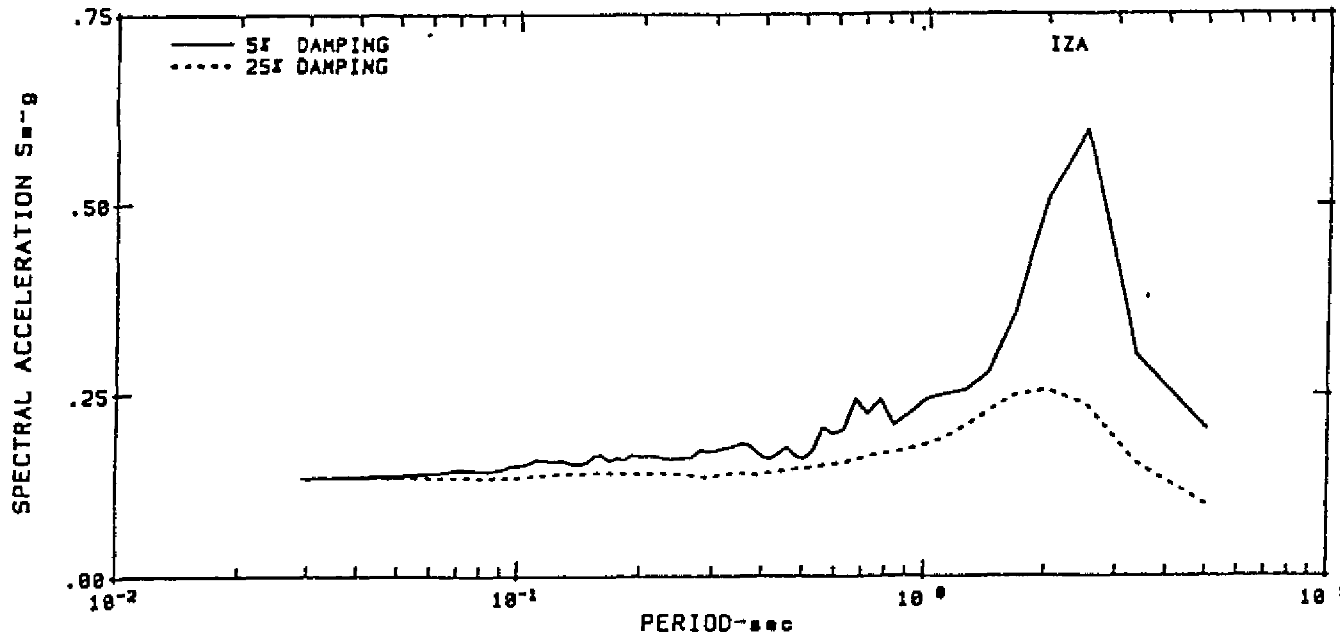


Figure 6. Response Spectra Calculated Using the 70-Second Record Designated IZA

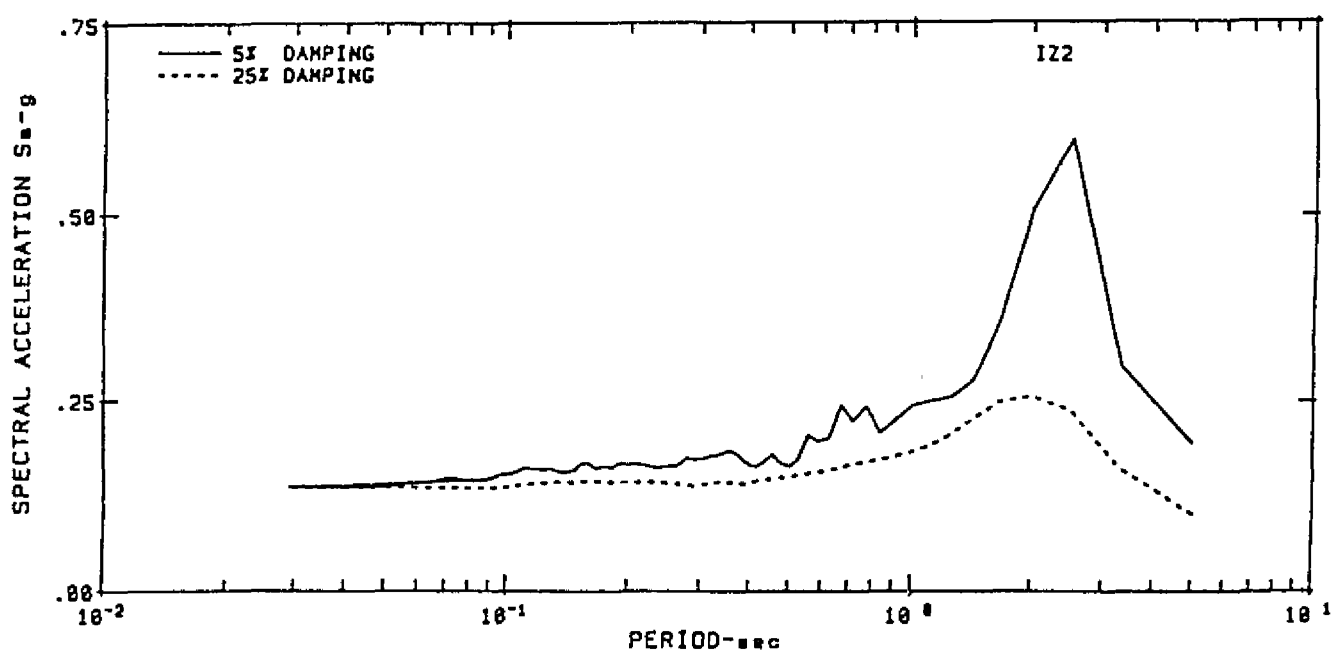


Figure 7 Response Spectra Calculated Using the 35-Second Record Designated IZ2

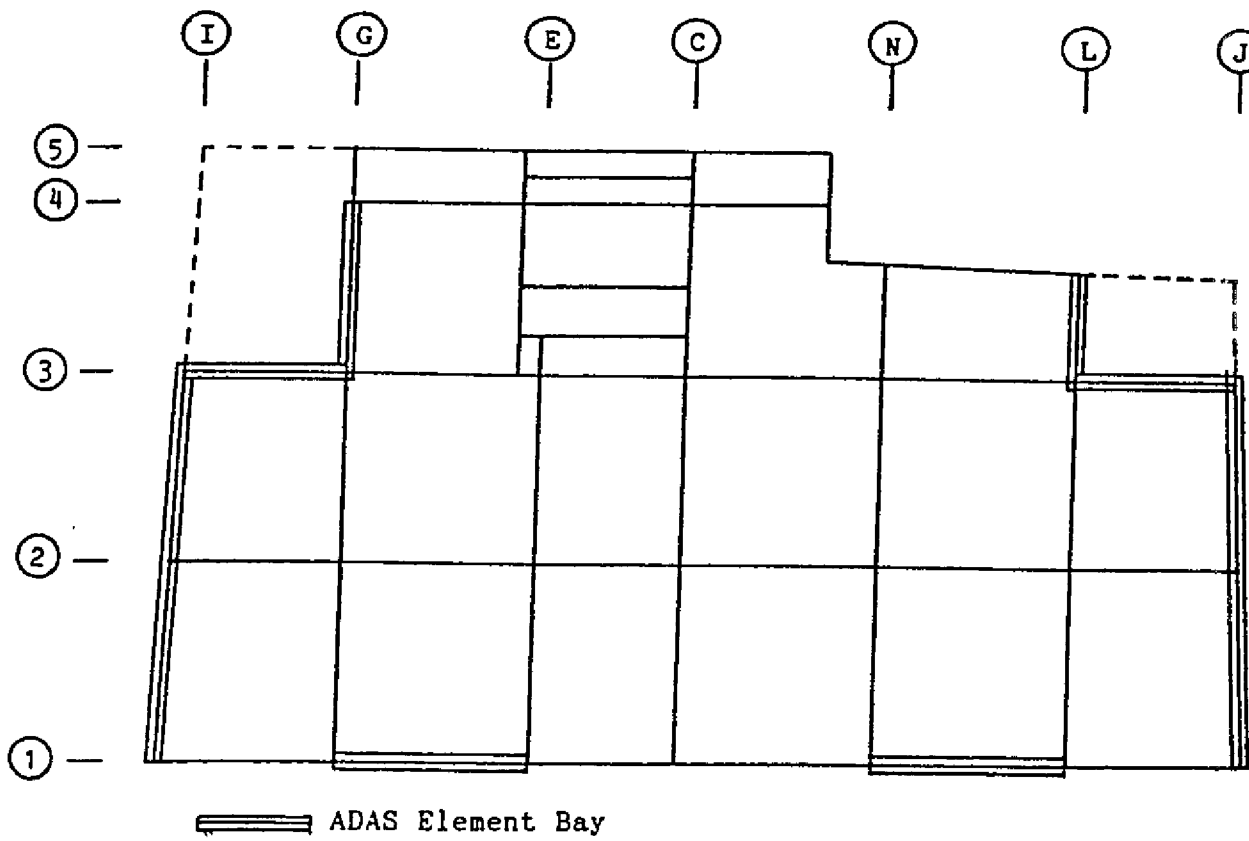


Figure 8 Schematic Plan Showing Locations of ADAS Bays in Izazaga #38-40 Building (Typical Floor Plan)

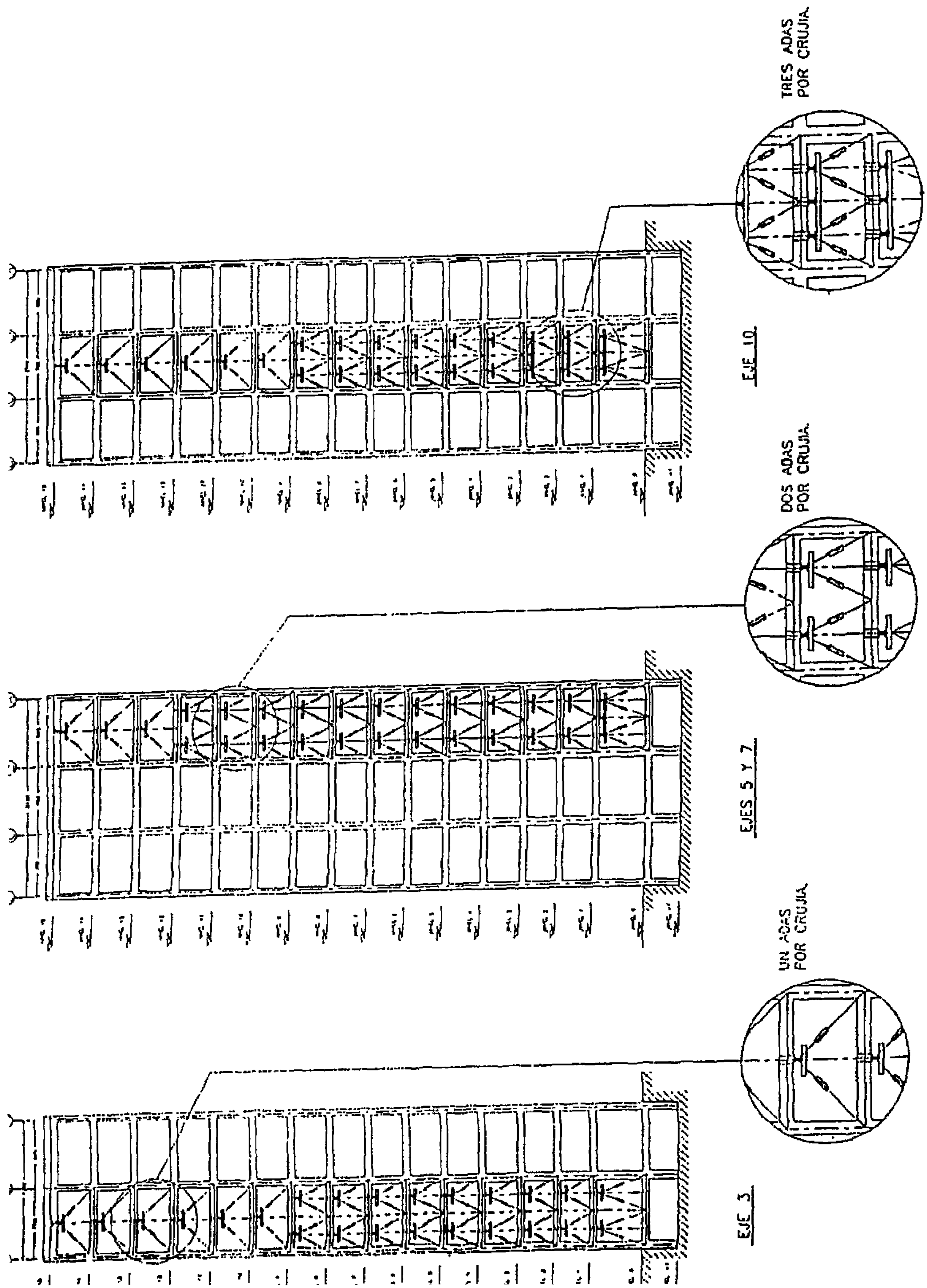


Figure 9 Typical Arrangement of braced Bays

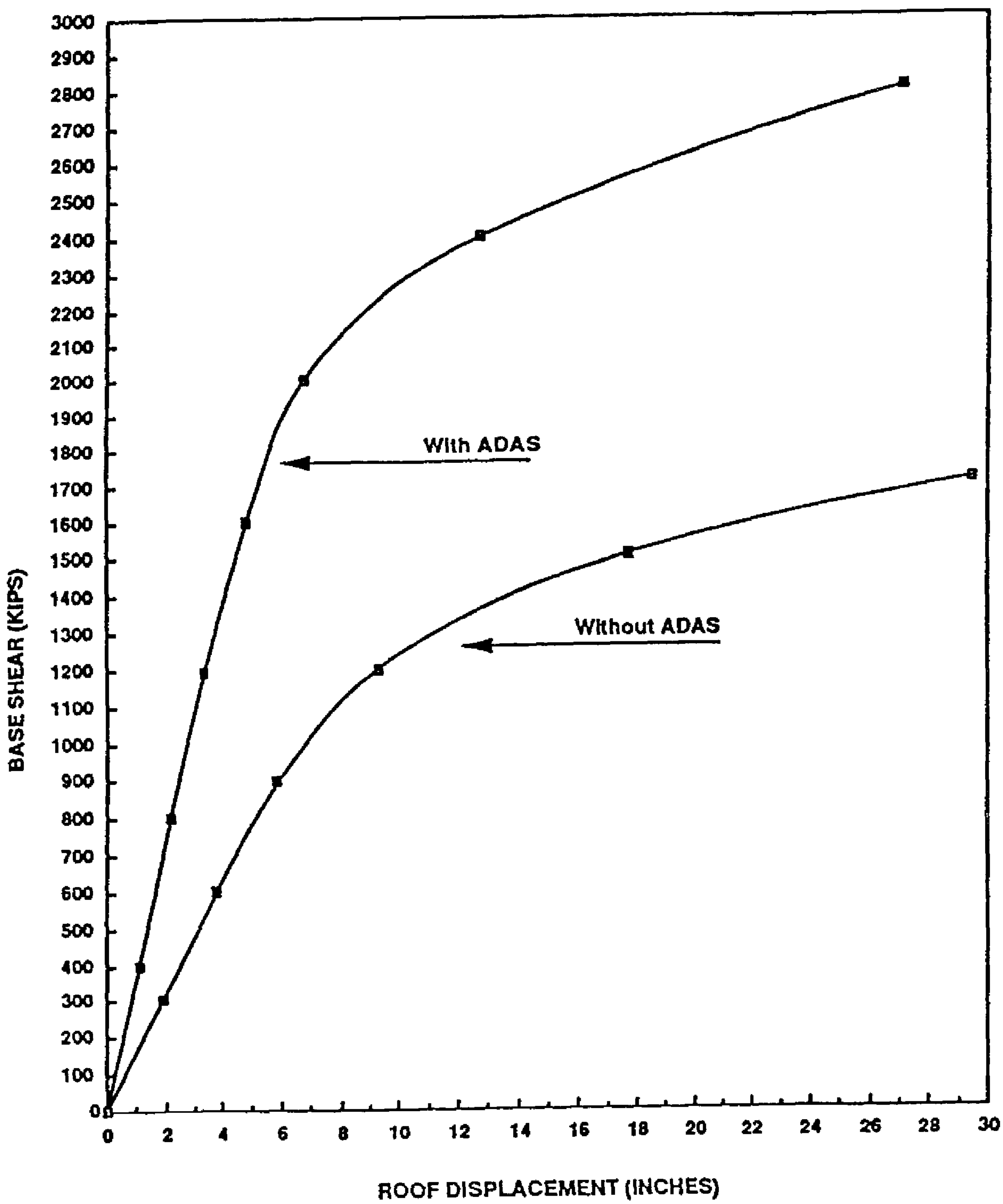


Figure 10 Base Shear vs Roof Displacement for Column Line 1

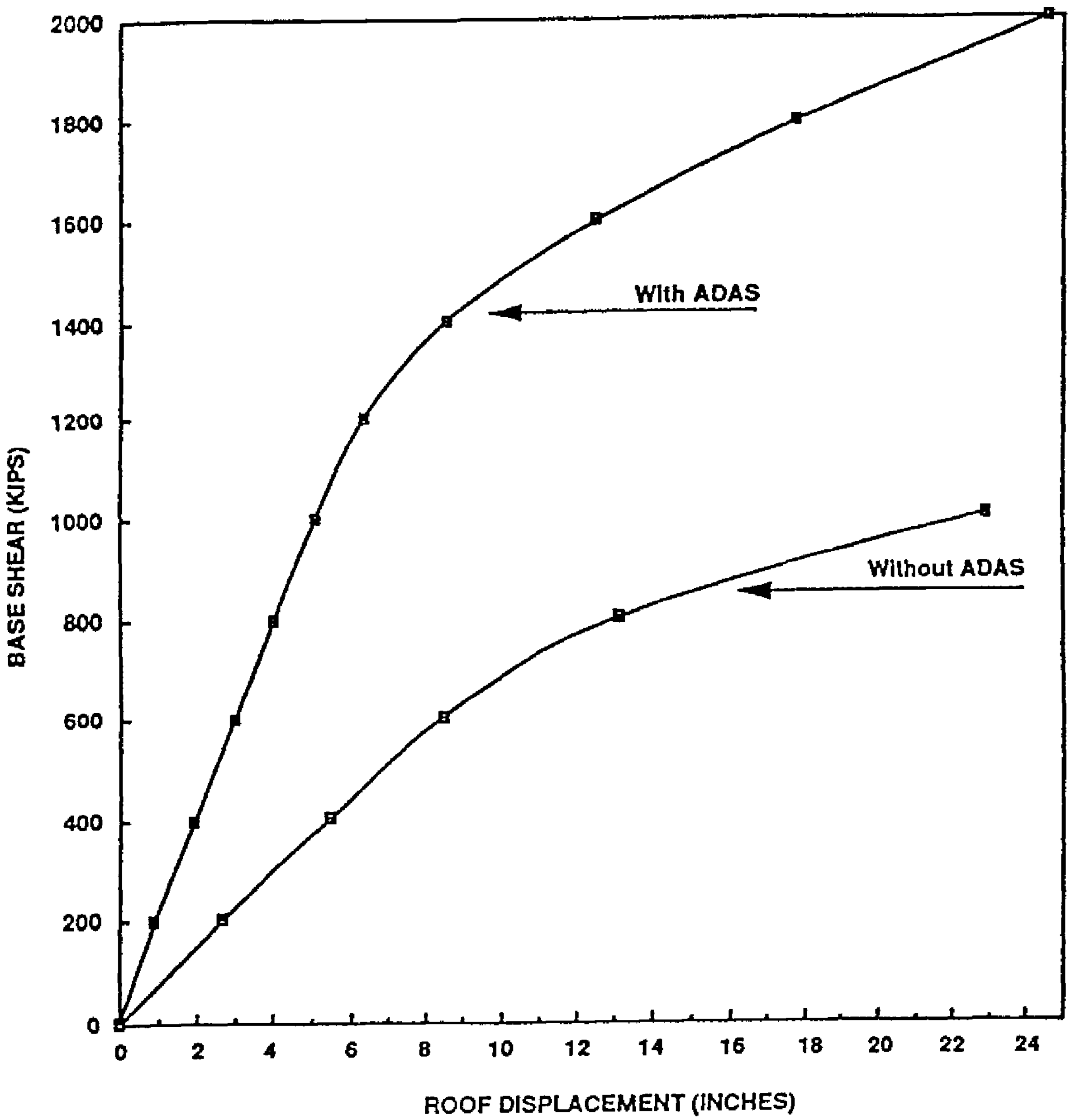


Figure 11 Base Shear vs Roof Displacement for Column Line 3

Figure 12 Photo Cardiology Hospital Building, Front

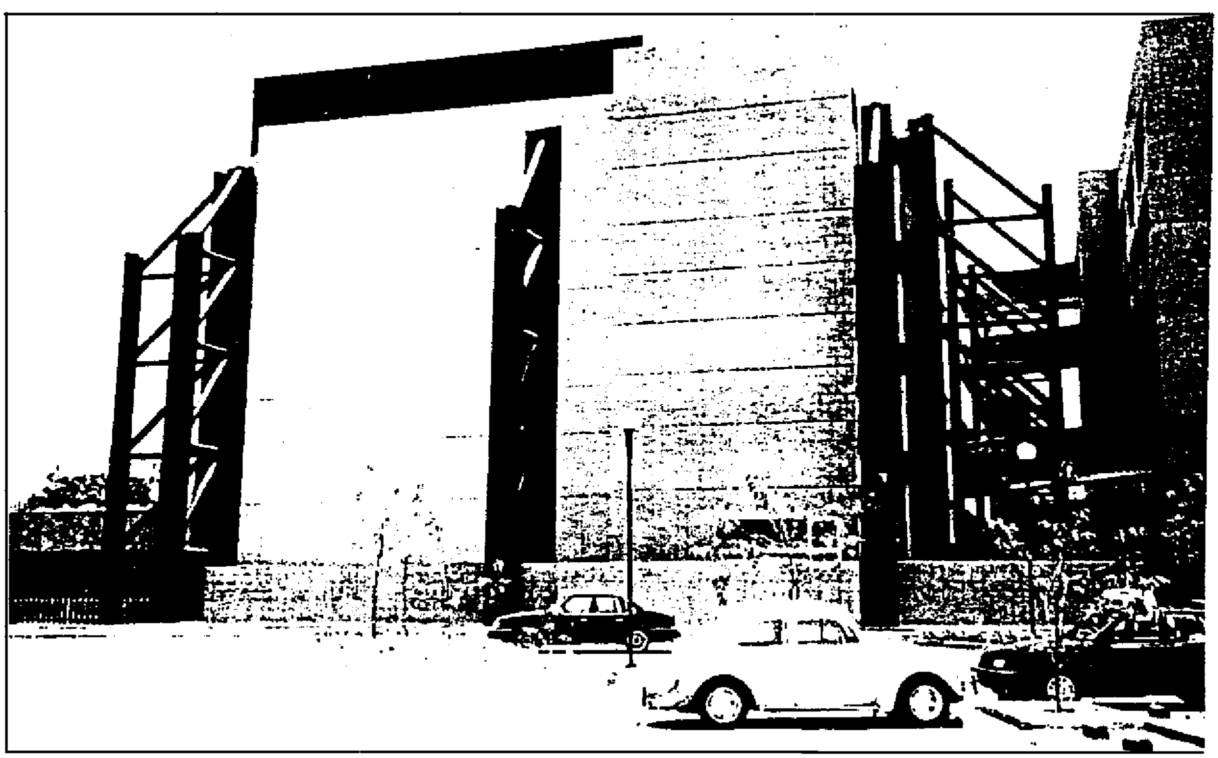


Figure 13 Photo Cardiology Hospital Building, Back

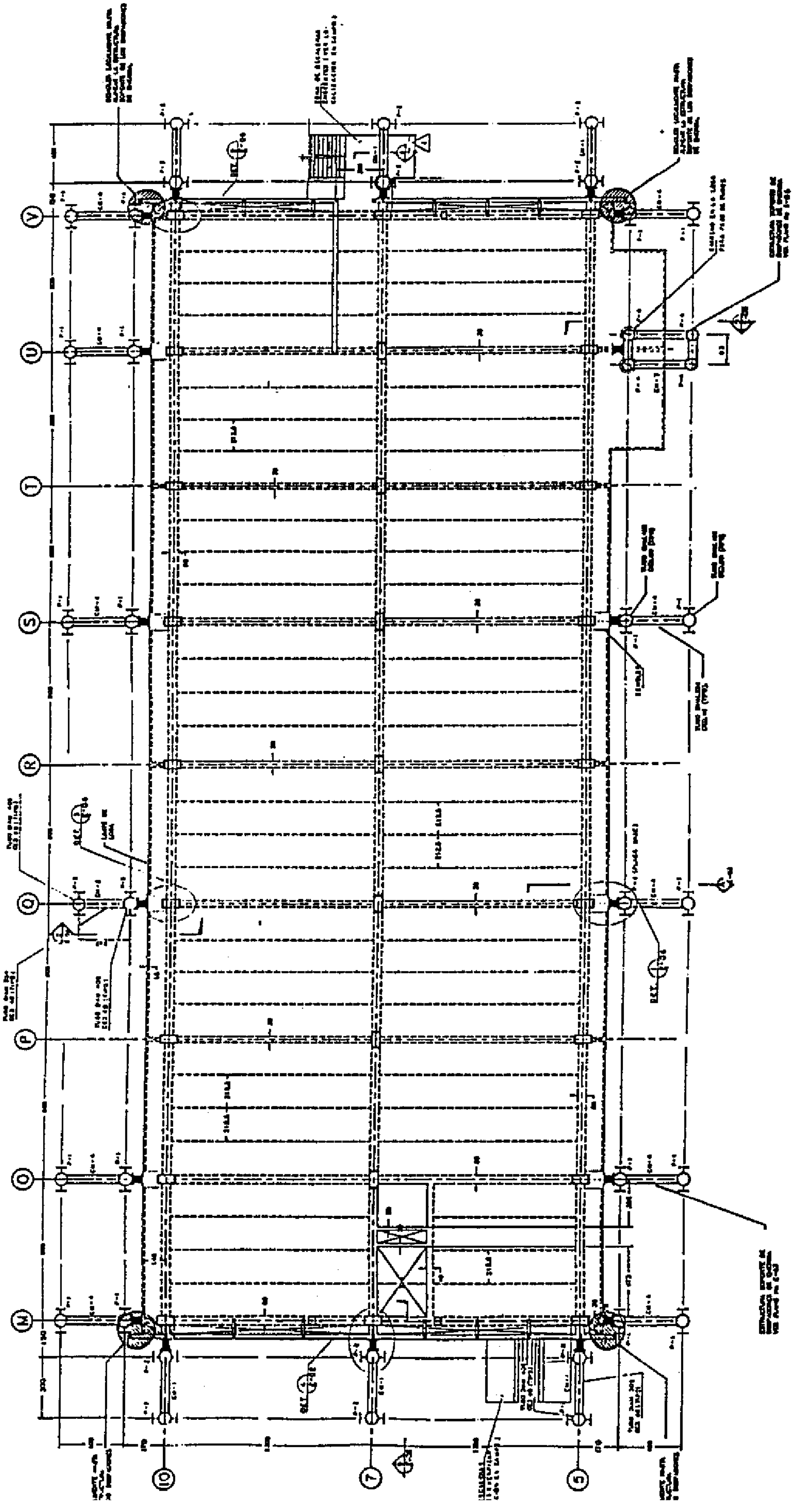


Figure 14 Basic Retrofit Scheme Plan

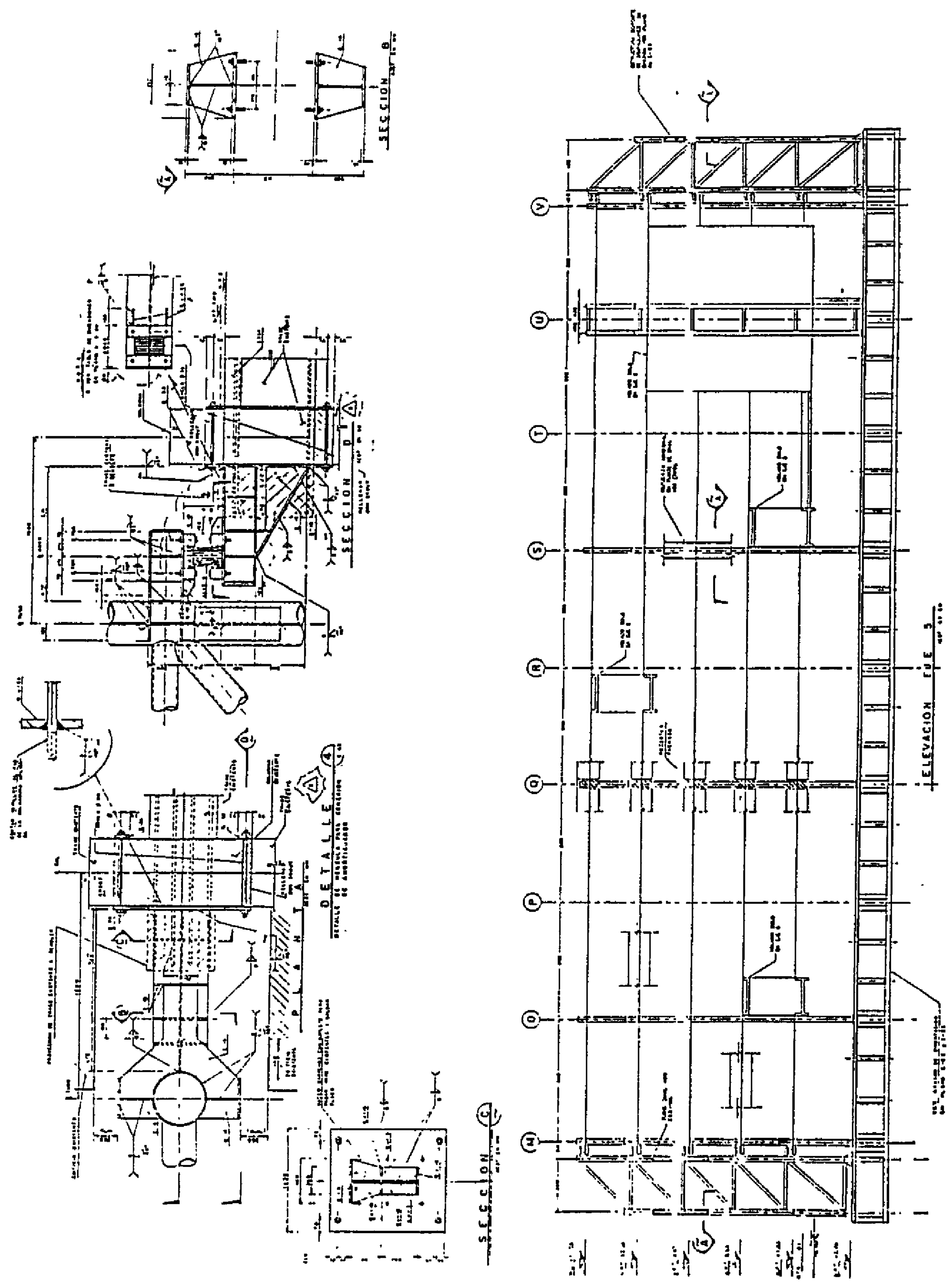


Figure 15 Basic Retrofit Scheme (Elevation)

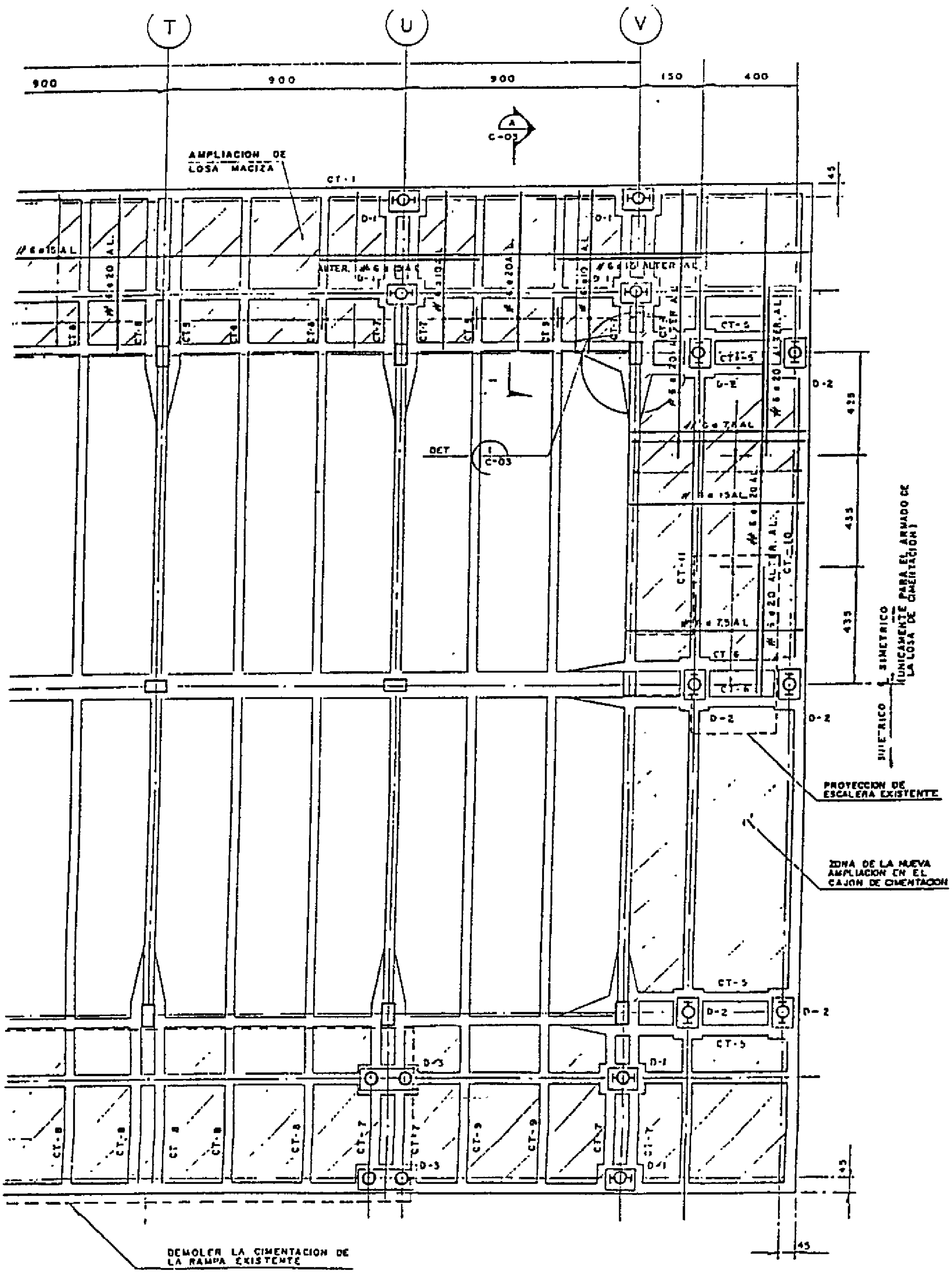


Figure 16 Foundation Detail

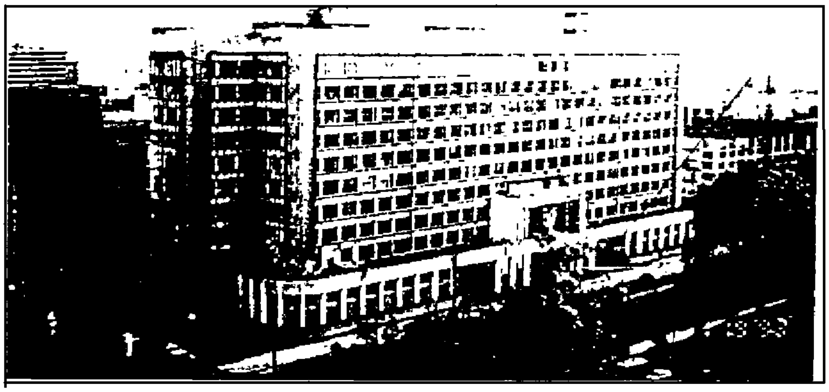


Figure 17 Photo IMSS Reforma Building, Front

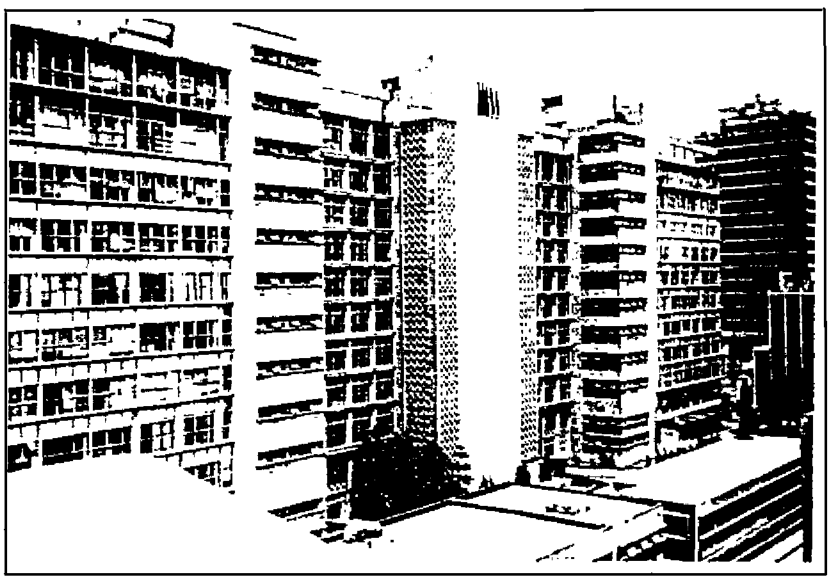


Figure 18 Photo IMSS Reforma Building, Back

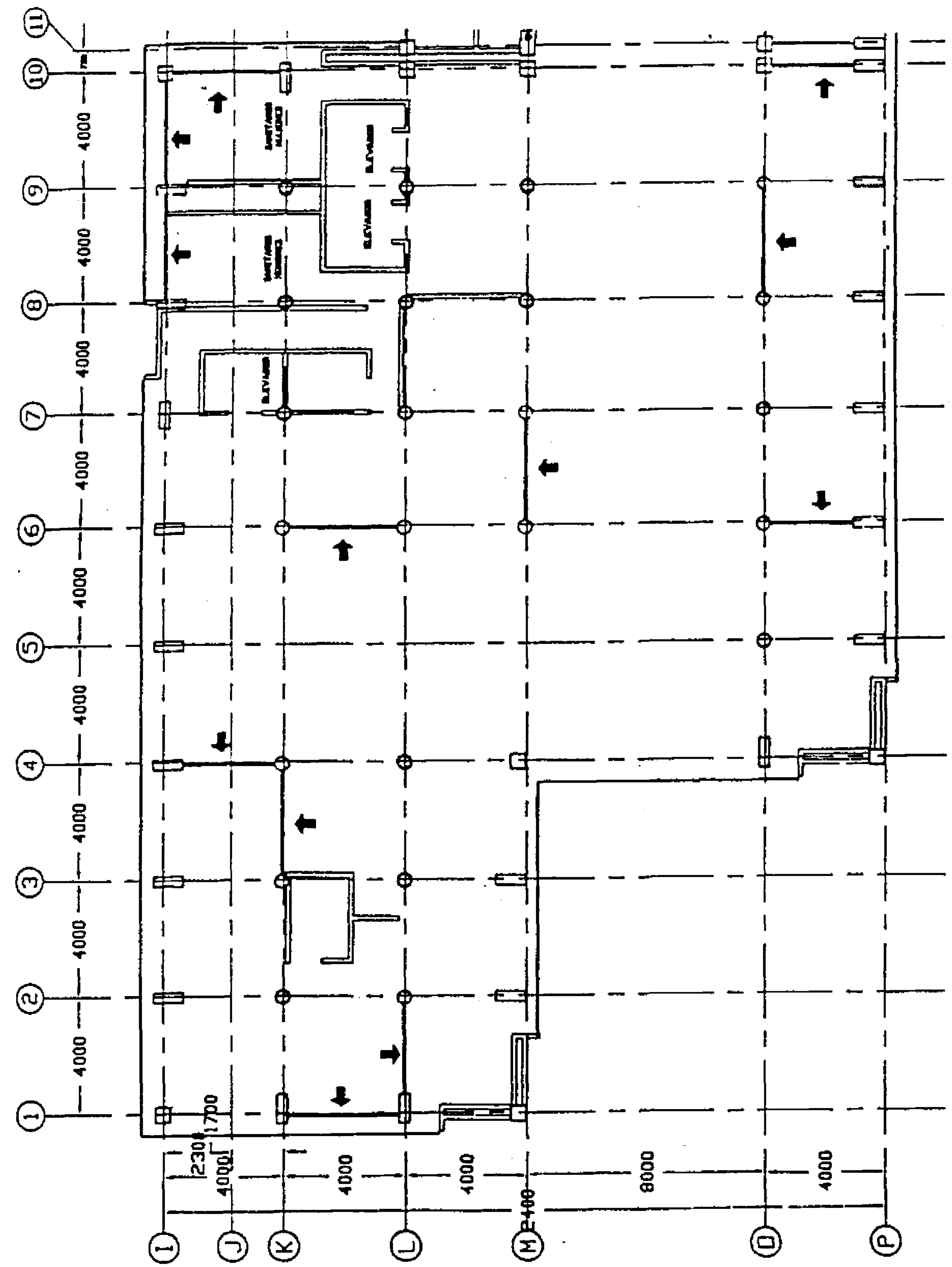


Figure 20 Plan Showing Locations of ADAS Bays in IMSS Reforma Building 1 (Lower Level-to-Roof)

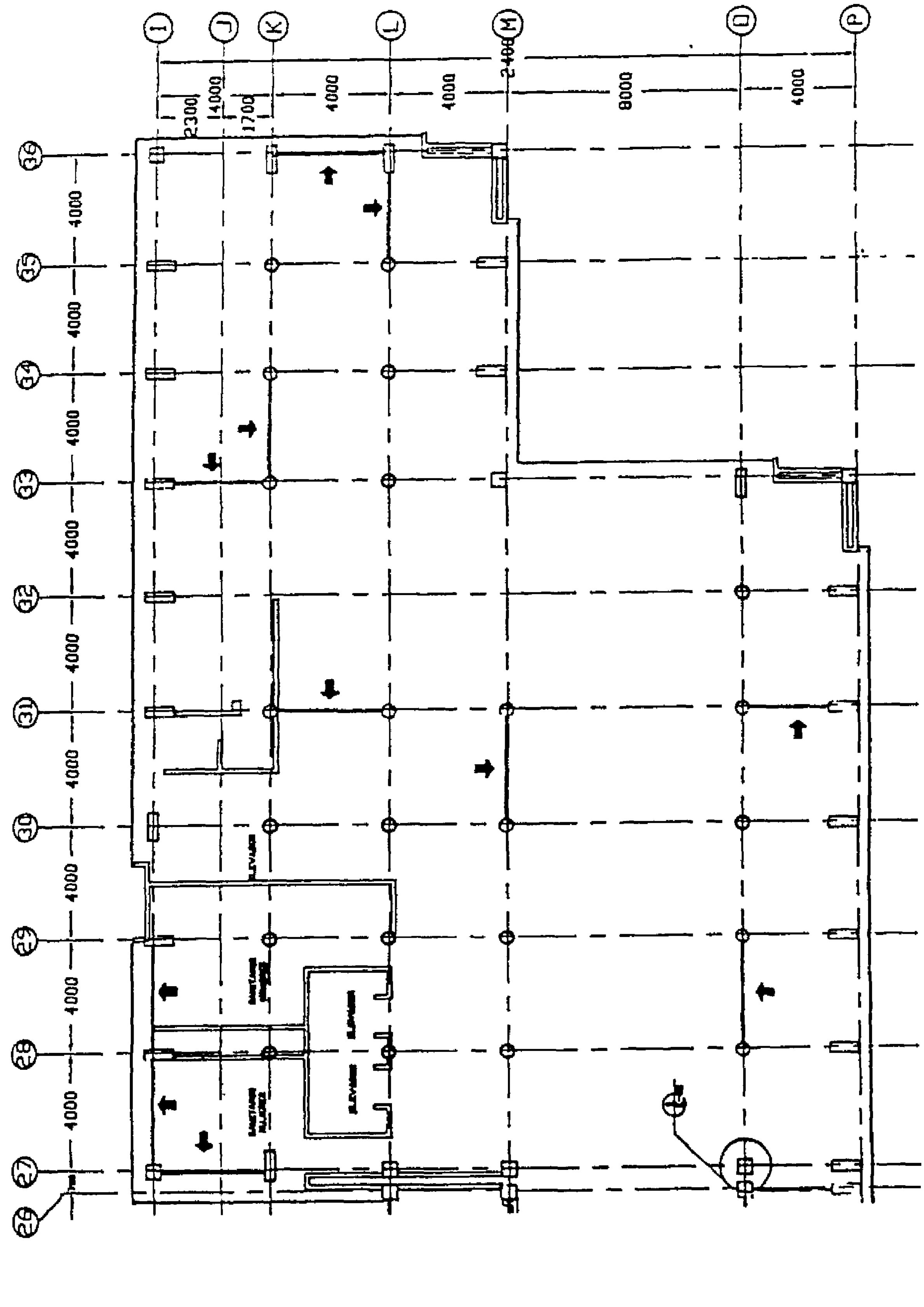


Figure 21 Plan Showing Locations of ADAS Bays in IMSS Reforma Building 3 (Lower Level-to-Roof)

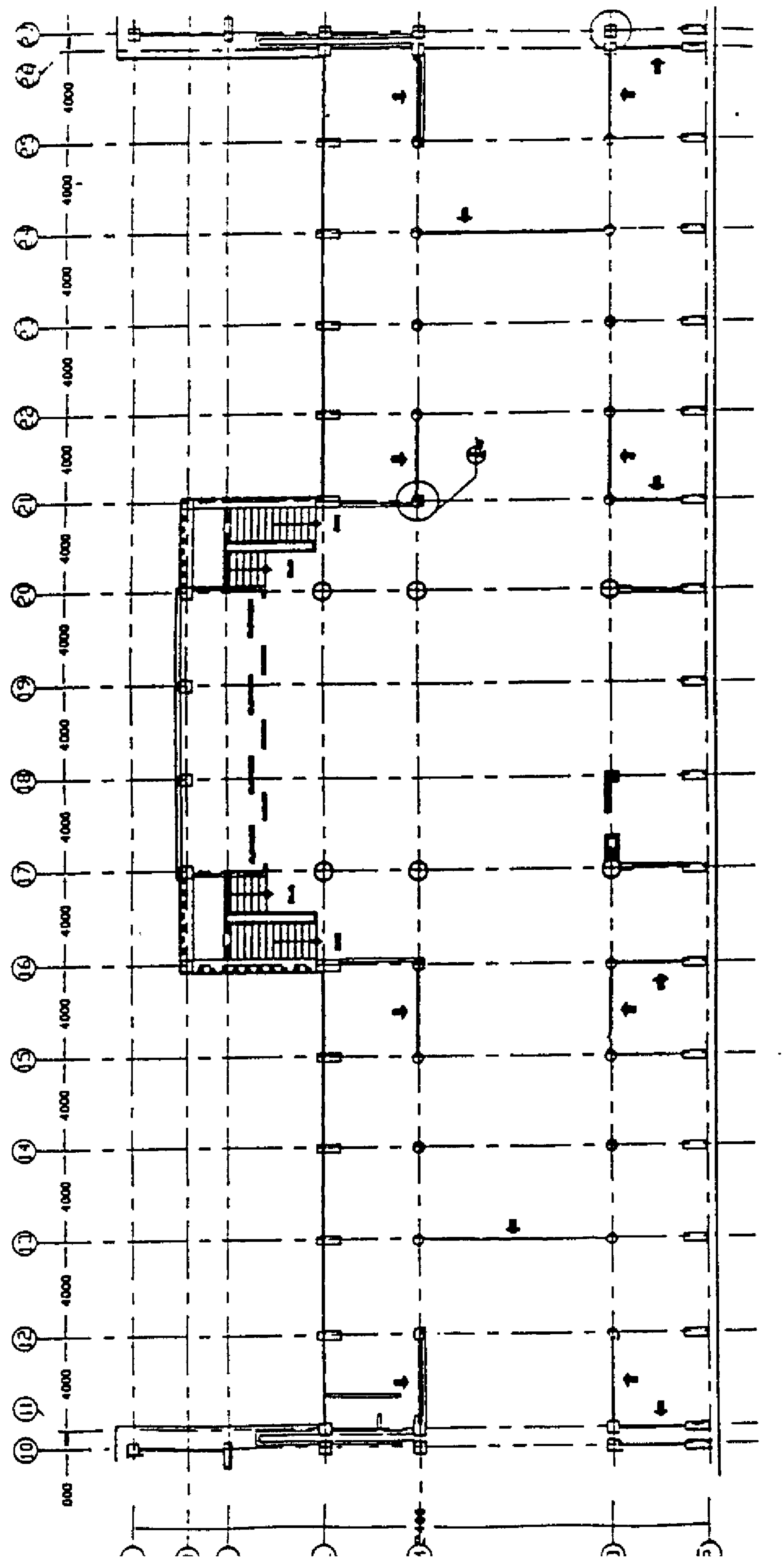


Figure 22 Plan Showing Locations of ADAS Bays in IMSS Reforma Building 2 (Level N1-to-Roof)

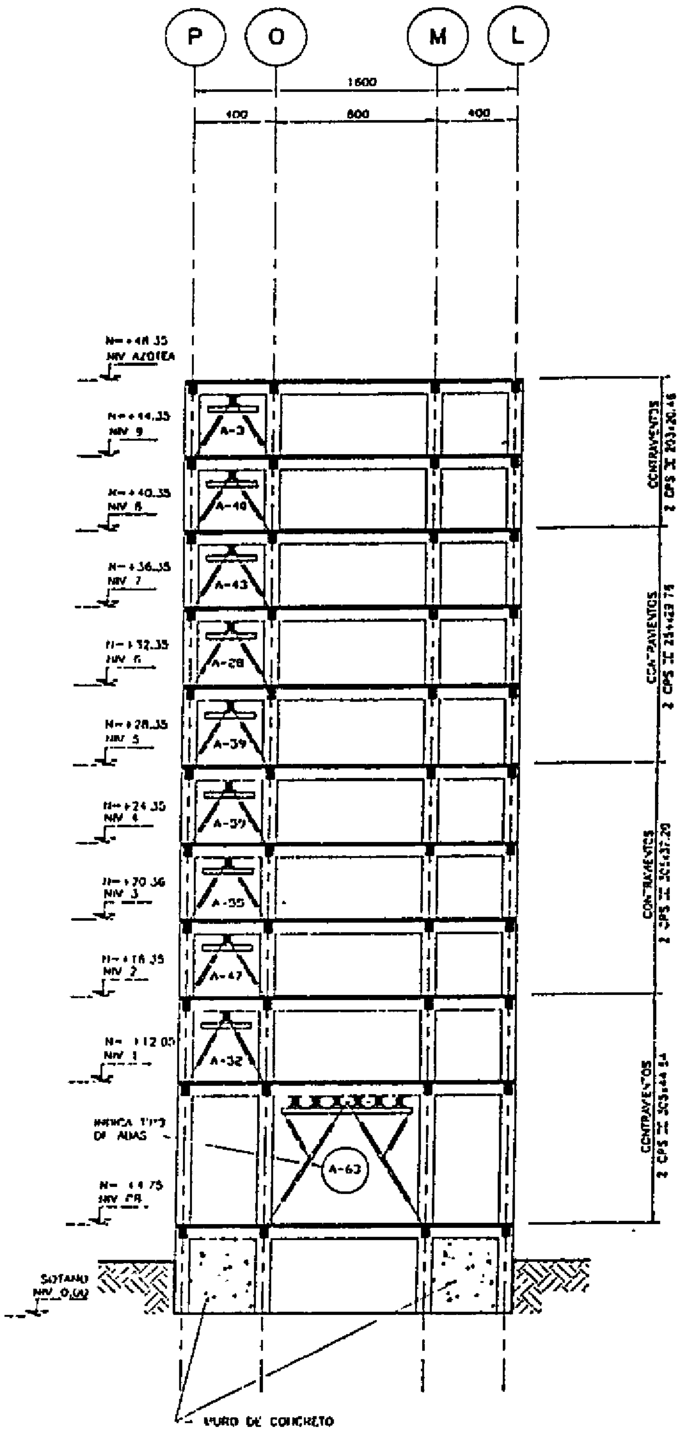


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Figure 23 Typical Bracing Arrangement IMSS Reforma Building

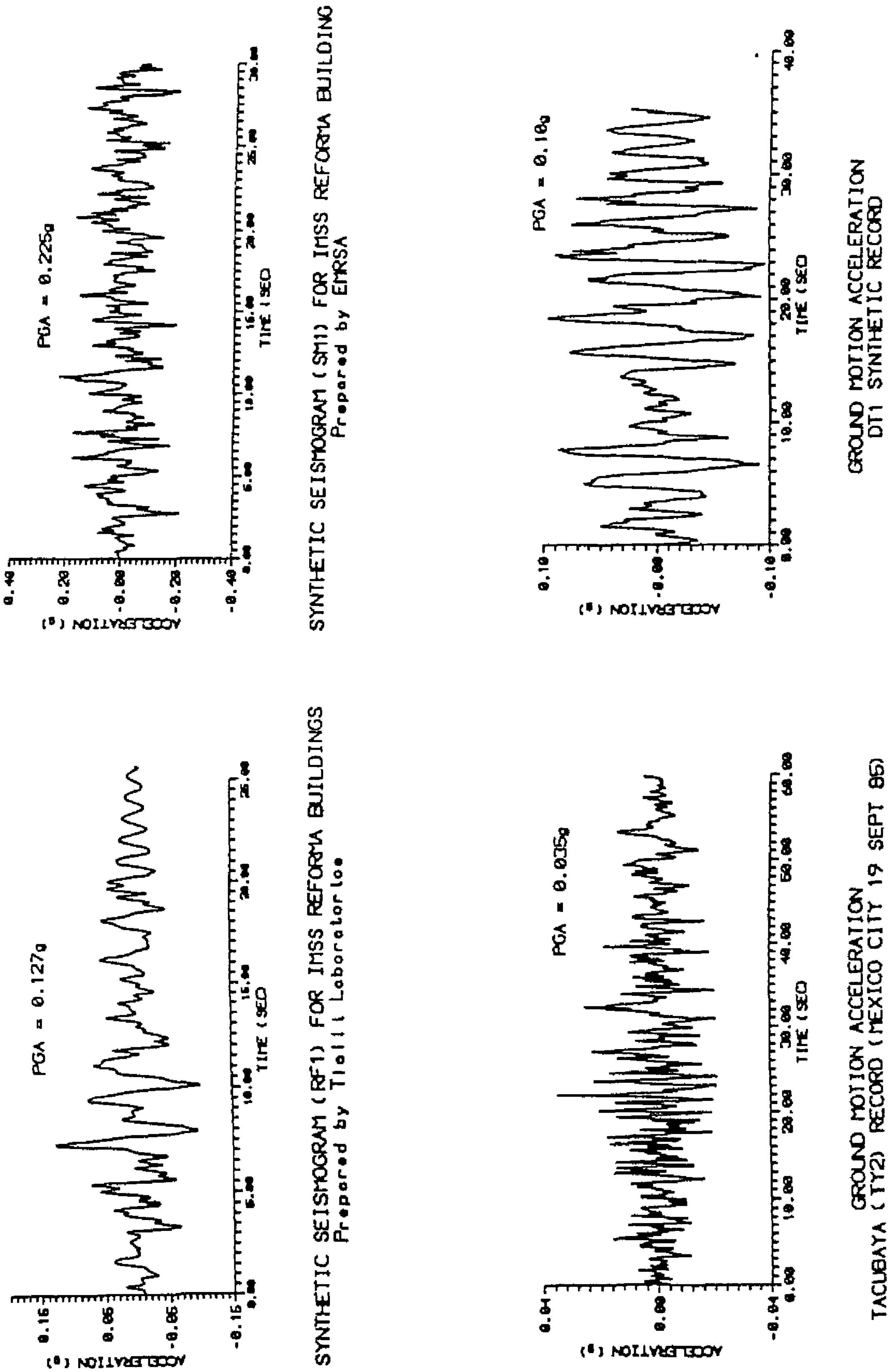

Figure 24 Accelerograms (Unscaled) for Earthquake Records Used for ADAS Design Evaluation

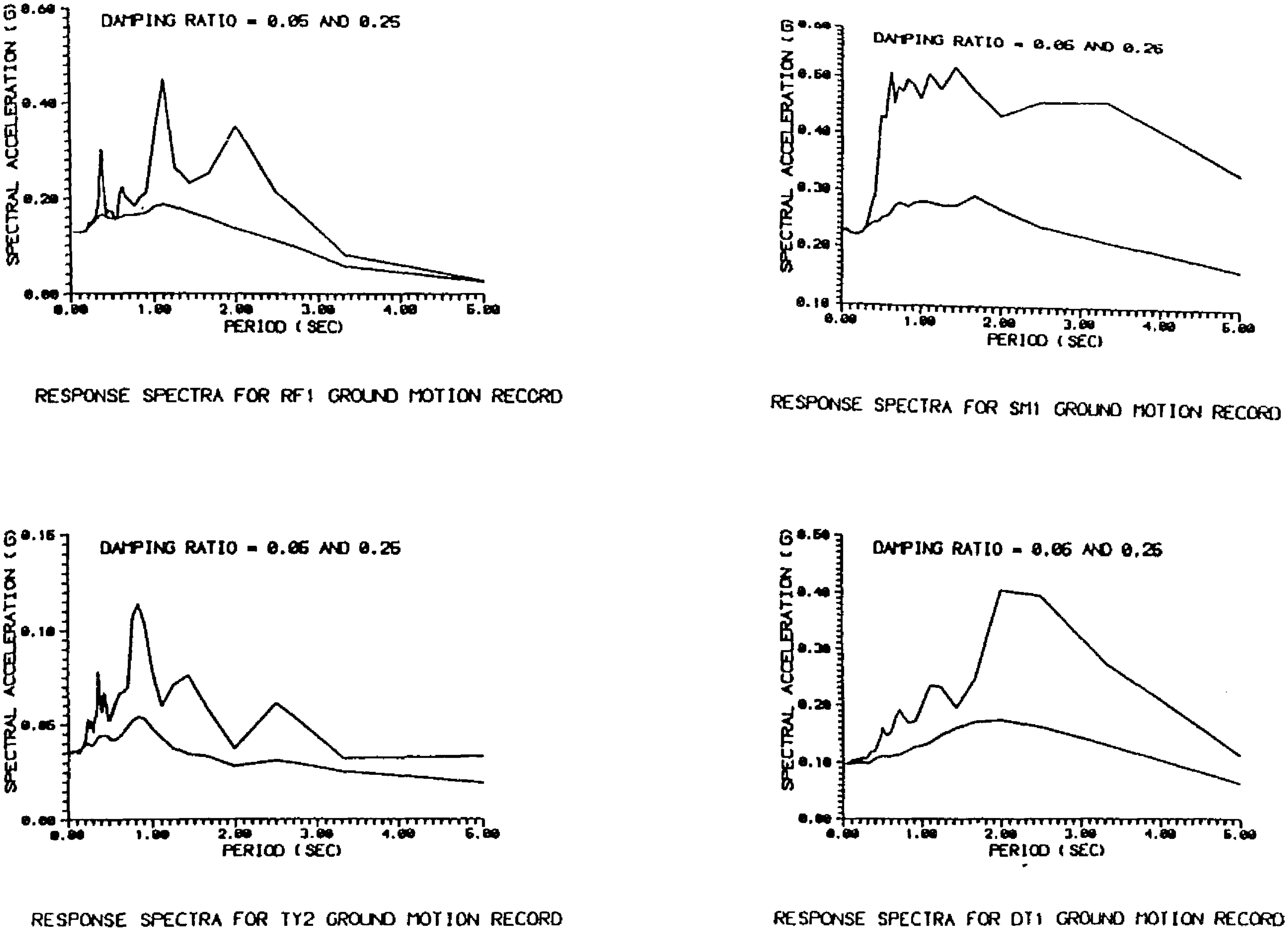

Figure 25 Response Spectra (Unscaled) for Earthquake Records Used For ADAS Design Evaluation

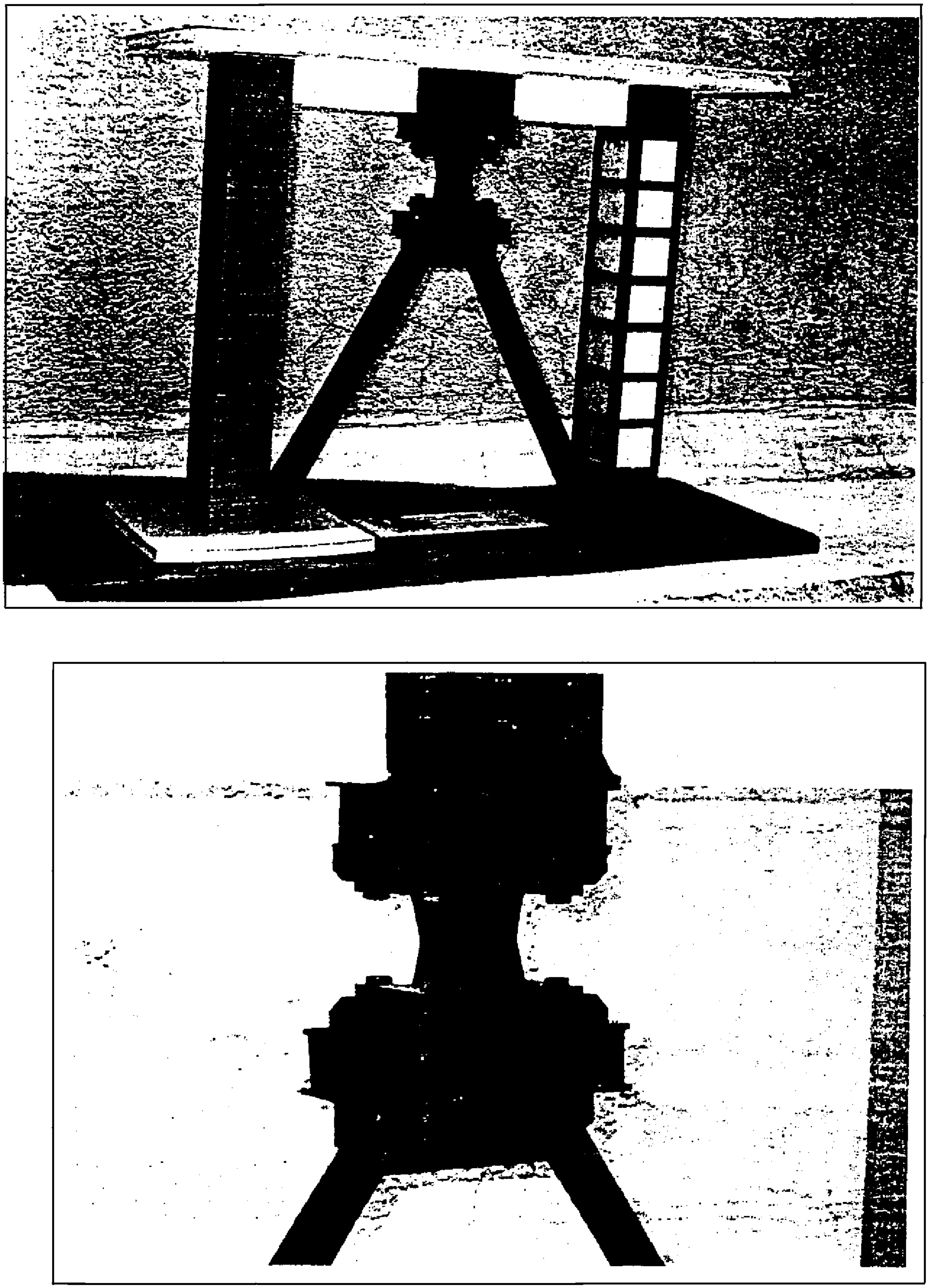

Figure 26 Typical Connection of One Single ADAS Frame

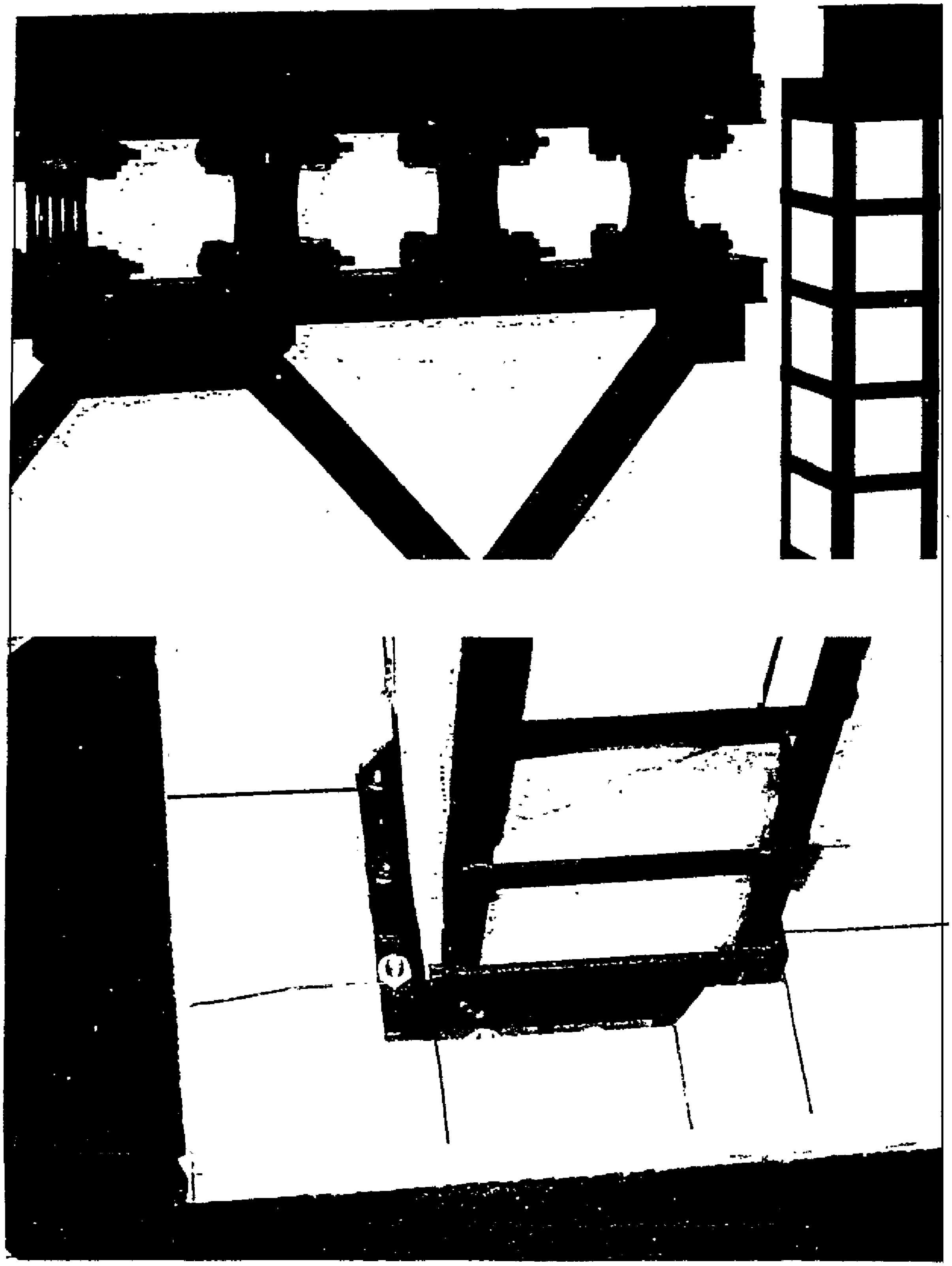

Figure 27 Typical Connection Detail and Column Jacketing for a Multiple ADAS Frame