

Engineering analysis of earthquake damage in catalogue-like form: Case-study of Eastern Kazakh earthquakes of 1990

A.S.Taubaev & E.T.Kenjebaev
KazNIISA, Alma-Ata, Kazakhstan, GUS

E.Hampe, H.-G.Schmidt & J.Schwarz
College for Architecture and Civil Engineering, Weimar, Germany

ABSTRACT: Results of an engineering analysis of structural damage in the Eastern Kazakh earthquake region are presented. The investigations of the German-Kazakh working group should contribute to a systematic documentation of available information in a catalogue-like form. The elaborated tools and manuals should support the re-interpretation of damage patterns, the determination of main damage contributing factors and the systematic summarization of available information.

1 INTRODUCTION

In 1988 a German-Kazakh research group was established to cooperate in the field of the engineering analysis of structural damage and to develop manuals in a catalogue-like form.

It was intended to include damaging earthquakes from the territory of the former Soviet Union into this work (Kenjebaev et al. 1990). Furthermore, it was decided that also actual events of moderate intensity should be incorporated into the investigations, recognizing the need of documentation of results and the benefit of the lessons those events could exhibit, practically.

2 EAST KAZAKH EARTHQUAKES OF 1990

The region of South and South-East Kazakhstan is characterized by an increased seismic activity. In the last 100 years heavy damaging earthquakes occurred in 1887 (magnitude 7,3) and in 1889 (magnitude 8,4).

On June 14, 1990 a comparatively moderate earthquake was registered in the Eastern Kazakhstan which was followed on August 3, 1990 by an aftershock of similar intensity. The epicenters of the earthquakes were determined near the village Saisan on the basis of information from the Chinese and Kazakh recording networks.

- * Data of the main shock (June 14, 1990):
magnitude: $M=6,9$; focal depth: $h=35$ km
coordinates of epicentre: $47^{\circ}57' N / 85^{\circ}00' E$
- * Data of the aftershock (August 3, 1990):
magnitude: $M=6,3$; focal depth: $h=20$ km
coordinates of epicentre: $47^{\circ}48' N / 84^{\circ}46' E$

Fig. 1 shows a part of the zoning map of the former Soviet Union illustrating the contours of isolines of intensity. In the past the southern region of the Saisan Sea referred to

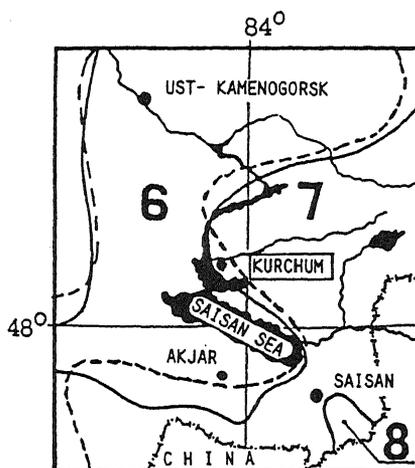


Figure 1. Parts of seismic maps according to the Soviet codes SNiP P-A.12-69 (—) and SNiP P-7-81 (---)

a seismic zone of an intensity 8°; after revision of the seismic map in 1978 the level of seismicity postulated for that region was reduced to an intensity of 7° (MSK). Similarly, the level of seismicity (in terms of intensity) of the town Kurchum was reduced from 7 to 6° (dashed line in Fig. 1).

The effects of the earthquakes were noticed within an area of 100000 km² (i.e. Ust-Kamenogorsk, Novosibirsk) which was uncommonly extended with regard to the amount of energy release. This could be explained by the geohydrological peculiarities along the system of river Irtisch.

As a result of the engineering analysis of damaged buildings, an intensity of 7° (MSK) was assessed for the town Kurchum, indicating

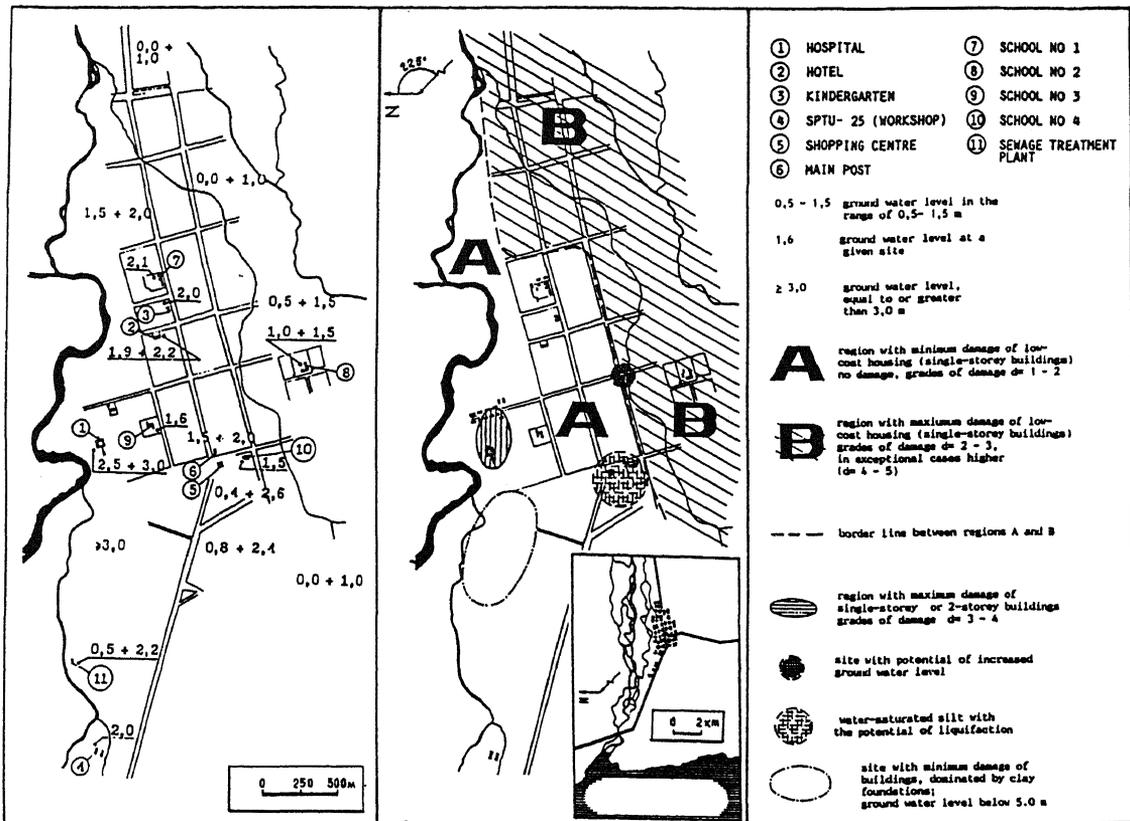


Figure 2. City map of town Kurchum including information on geohydrology, sites of inspected buildings and zones of different damage (vulnerability) of buildings

the need of a correction of the currently proposed seismic zoning map (see actual version in Fig. 3).

Instrumental registrations within the mainly affected area are not available to explain amplification effects, directly.

3 ENGINEERING ANALYSIS OF DAMAGE

3.1 Geological and geohydrological aspects

The mainly affected areas are lowlands alongside the Saisan Sea (Fig. 1). The geological and subsoil conditions can be classified as about 30 m alluvial deposits, including boulders (25 percentage of volume).

The geohydrological conditions in the town Kurchum are illustrated in Figure 2. They are dominated by the branches of the river Kurchum.

The level of ground water table can be expected in depths of 0,6 to 4,0 m below the ground surface. As result of the preliminary geohydrological investigations, the area of Kurchum can be classified into two zones:

- zone in Southern, South-Western and Eastern direction with high level of subsoil water

(0 to 1 m), locally outcropping on the surface

- zone in Northern and North-Eastern direction with medium level of subsoil water (1,5 to 2,5 m)

3.2 Types of buildings in the study region

The engineering analysis of structural damage was performed in the town Kurchum (10 000 inhabitants, department centre of the East Kazakh district), Fig.1.

The predominant types of buildings can be characterized as one- or two-storey low cost housings which were built without any antiseismic measures.

The public buildings (schools, hospital, hotel, post office etc.) were built in masonry or prefabricated reinforced concrete wall construction. A detailed description of these buildings is given by Kenjebaev et al. (1991).

Fig. 2 gives an impression of the map of Kurchum and of the sites of the buildings, selected and being relevant for engineering analysis. As a whole, 11 positions of buildings come into consideration. The level of

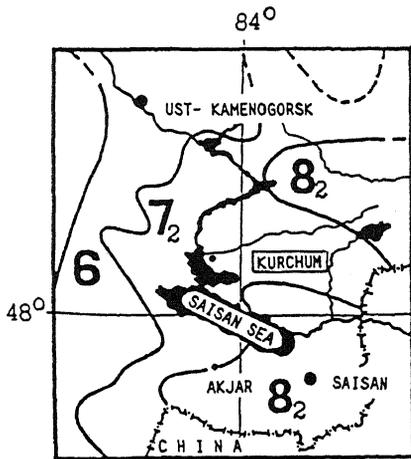


Figure 3. Zoning map of East Kazakhstan proposed after the earthquakes in 1990

ground water table at these sites can be taken from Fig. 2.

3.3 Results of damage inspection

According to the analyzed structural damage the map of the town could be subdivided into two main zones which are nearly identical with the zones of qualitatively different levels of ground water table (Fig. 2):

- zone A: region with minimum damage of low-cost housing; typical grades of damage $d=1$ to 2 (according to MSK-81 intensity scale)
- zone B: region with maximum damage of low-cost housing; typical grades of damage $d=2$ to 3 and in exceptional cases also higher ($d=4$ to 5).

Additionally, smaller areas are circled on which special remarks to the subsoil conditions and the level of damage could be formulated. In the centre of the town a region of ground conditions is circled which is characterized by a thick layer of water-saturated silt with the potential of liquefaction. For the public buildings in this region (shopping centre, post office and school No 4; sites 5, 6 and 10 in Fig. 2) pile foundations were provided.

Therefore it was possible to mark border lines between zones which should be recognized for future siting. The map in Fig. 2 is one of the final results of the engineering analysis.

Subsequently examples or basic elements of this analysis are presented.

4 EXAMPLES OF ANALYZED BUILDINGS IN THE TOWN KURCHUM

From the engineering point of view the buildings of the hospital (site 1) and the

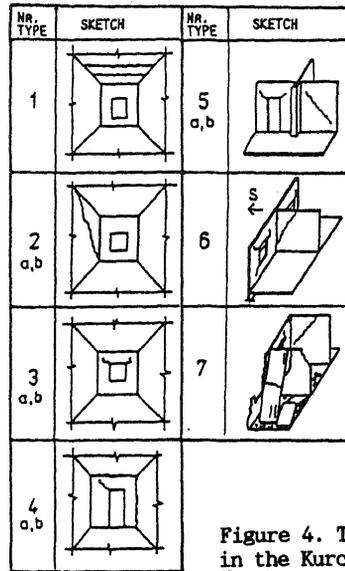


Figure 4. Types of damage in the Kurchum hospital

schools (sites 7 to 10 in Fig. 2) were of special interest.

4.1 Example 1: Hospital

The hospital complex was constructed according to a standard project (without any antiseismic measures) in 1986; it consists of five blocks (see upper part of Fig. 5). There were no antiseismic joints provided between the blocks.

The blocks A, B and E are four storeys high (the fourth floor is a technical service storey). The blocks C and D are two storeys high.

The load-bearing (lateral) and the non-bearing walls are made of brickwork.

Floor slabs, staircases and lintels are made of prefabricated r.c. elements.

The building has concrete strip foundations with different depths of embedment (Fig. 6). Blocks B, D and E are sited on reclaimed land (filling).

As it can be seen in Fig. 2, the hospital is situated in a region where a maximum damage of single- and two-storey buildings was registered (grades of damage $d=3$ to 4).

It was intended to assess the structural damage by a procedure in three steps leading to the following results:

- (1) detailed description of damage (predominant types of failure; width of cracks or size of drifts),
- (2) determination of the grades of damage for each storey and within each block
- (3) determination of the grades of damage for each block and the entire building complex.

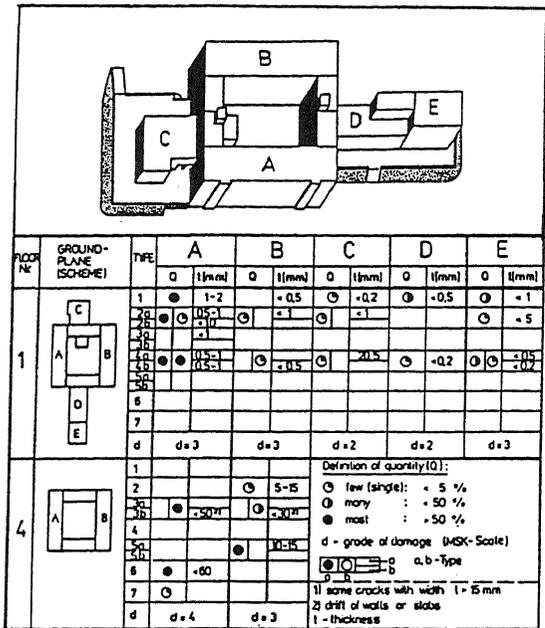


Figure 5. Results of the damage inspection of the hospital according to the reference types of damage pattern

For the systematic description of damages seven types of damage patterns are distinguished, which are schematically shown in Fig. 4. (step 1). These types and their frequency of occurrence were elaborated for each block and within each storey (step 2). An extraction of summarized results is shown in Fig. 5.

During the earthquakes of June and August 1990 the hospital suffered damage of grades 2 to 4 (Fig. 5) according to MSK-81 intensity scale. Evidently the block A got major destruction and higher grades of damage.

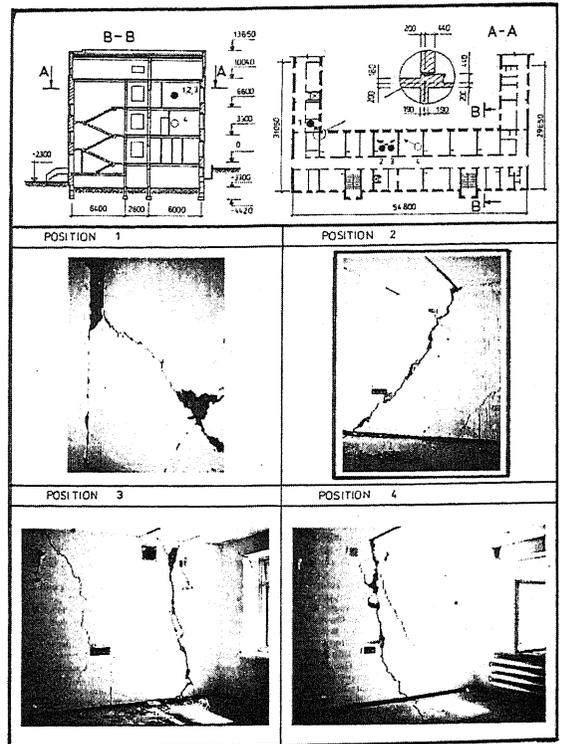
The aftershock aggravated the conditions of the building. From the comparison of structural damage it can be concluded, that the aftershocks increased the average damage by one grade.

Furthermore, it was intended to document the state of the damaged building and to derive the reasons of structural failure. For that purpose the spatial distribution of damage within the building was illustrated.

The photos taken at the inspection were incorporated into the elevations and plans (Fig. 6). These photos describe

- typical damage patterns of load-bearing and non-bearing walls (Fig. 6, Fig. 7)
- typical damage patterns of infills and piers between openings
- damage patterns, taken from both sides of walls and
- damage patterns, taken from the walls of storeys and the intermediate slabs.

In this way the results of analysis could be



(a) Typical damage patterns of load-bearing walls of the Hospital



(b) Detail of catalogue sheet: Position 2 (Type of damage No 2 according to Fig. 4)

Figure 6.

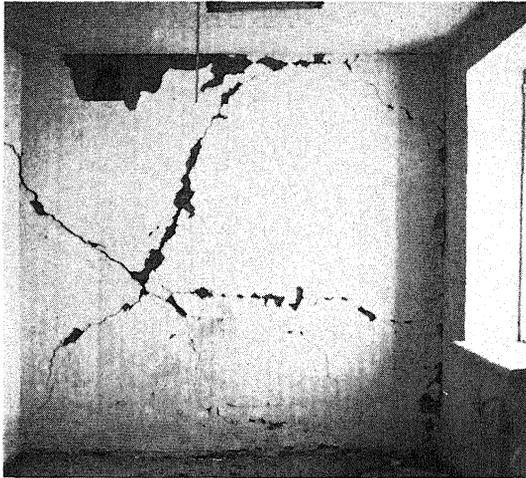


Figure 7. Typical damage patterns of non-bearing walls of the Hospital (3rd floor)

summarized in a catalogue-like presentation.

It seems to be possible to reinterpret the acting forces, the initialized structural resistance and its time-dependent deterioration. No doubt, the damage pattern itself is a good indicator for the inherent insufficiencies of the structural design.

The damage contributing factors are summarized by Kenjebaev et al. (1991) and are discussed in more detail within the sheets of the "Damage catalogue of the Saisan Earthquakes 1990" elaborated by the German-Kazakh working group (Taubaev et al. 1992).

After the detailed inspection and analysis of the damaged hospital it was decided to dismantle the third and fourth storeys of the blocks A, B and E and to strengthen the basement and lower floors.

4.2 Example 2: Schools

The four schools (pos. 7 to 10 in Fig. 2) of the town Kurchum were inspected following the same procedure explained before.

With respect to the quite different grades of damage of the structures three aspects were of special importance:

(1) The schools were located in regions of different subsoil conditions and levels of ground water (see Fig. 2) which lead to a non-uniform and significant site-dependent amplification of low-intensity ground motion.
 (2) The buildings satisfied the demands for regularity in a quite different quality, whereas the level of regularity was defined by the regularity in plane, the distance of stiffening walls, the arrangement of openings and the type of coupling between walls, slabs and foundations.

(3) There were serious differences in quality of workmanship, material and provision of antiseismic measures.

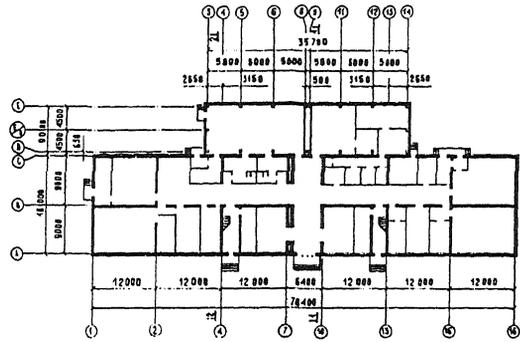


Figure 8. Regular plane of the school No 4

The following decisions were derived from the engineering analysis of structural damage - repair of school No. 4 (damage grade $d=1$) - repair and strengthening of school No. 3 ($d=2$ to 3) and school No 1 ($d=2$) and - demolition of school No 2 ($d=3$ to 4).

The extensive damage of school No 2 is illustrated in Figure 12 (example 3 of catalogue sheets).

The failure of the foundation and the other structural parts (walls, slabs) was caused by insufficient quality of materials and the lack of antiseismic protection.

The good performance of school No 1 can be explained by the regular plane (Fig. 8) and the antiseismic design for a reference intensity of 7° (MSK) according to the previous zoning map OSR-1969 (see Fig. 1).

Because of the high importance of the buildings the national authorities decided to strengthen schools No 1 (Fig. 9) and 3 (Fig. 10) immediately. This decision was supported by the facts that schools themselves were without any additional seismic protection and that earthquakes of intensity of 8° cannot be excluded in the future.

5 DOCUMENTATION OF THE RESULTS OF ENGINEERING ANALYSIS OF EARTHQUAKE DAMAGE

Damage inspections often lead only to the estimation of economical losses (problems of insurance), the analysis of spectacular failures and the reassessment of seismic hazard. Nowadays, it seems to be necessary to collect all information which are available and to develop manuals for the interpretation of damage.

The results of the damage analysis of the German-Kazakh working group are presented in catalogue-like form. For the purpose of illustration examples of typical catalogue sheets are given in the Figures 11 to 14 demonstrating the different intention of information supply:

- description of the building design; plans and elevations, structural system

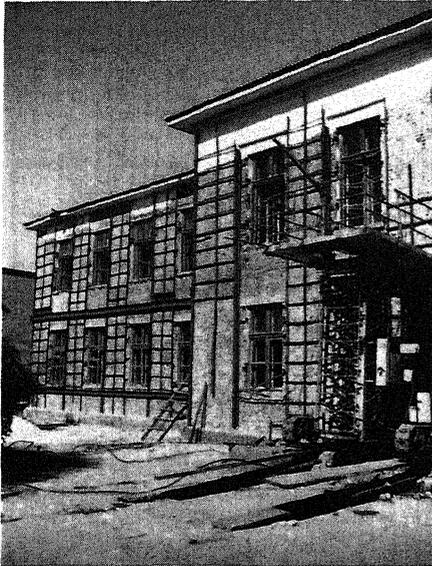


Figure 9. Strengthening of school No 1 with a steel skeleton of different profiles



Figure 10. Strengthening of piers between openings (school No 3)

(Fig. 11: buildings of agricultural education and training centre/ SPTU-25; building site No 4 in Fig. 3)

- description of damage pattern and mainly affected parts of buildings including fotos (Fig. 12: school No 2; building site No 8 in Fig. 2)
- re-interpretation of the stages of structural failure on the basis of damage contributing factors and determination of weak structural points (Fig. 13: building of service station of SPTU-25)
- generalization of results with respect to structural type, local subsoil conditions, use, regularity and orientational sensitivity of buildings (i.e. angle of incident seismic waves) (Fig. 14: investigations of all schools within the mainly affected area).

6 CONCLUSIONS

For the engineering analysis of structural damage earthquakes of moderate intensity could be of special interest. The advantages are verified using results of a damage inspection in the town Kurchum (Eastern Kazakh earthquake region), elaborated by a group of German and Kazakh experts:

- The affected area was limited and allowed a detailed analysis of damaged buildings.
- The level of damage (grades between 1 and 3) made it possible to specify the correlation between design, structural type, amplification effects and present damage patterns.

- For buildings of similar structural type and functional use the predominating influence of antiseismic construction and of subsoil conditions on the level and pattern of damage could be illustrated.
- The aggravation of the state of predamaged buildings caused by aftershocks of higher intensity could be specified.

The results of the damage inspection are summarized in a catalogue-like form including the fundamentals for engineering analysis (seismological, geological, geohydrological etc. aspects) and the observed earthquake effects. Within this catalogue the structural damage is referred to the damage contributing aspects.

The proposed catalogue-like presentation of the results seems to be well-suited for saving information after earthquakes. The international exchange and the distribution of those materials can also be regarded as a very helpful contribution to the UN- Decade of Natural Disaster Reduction (IDNDR).

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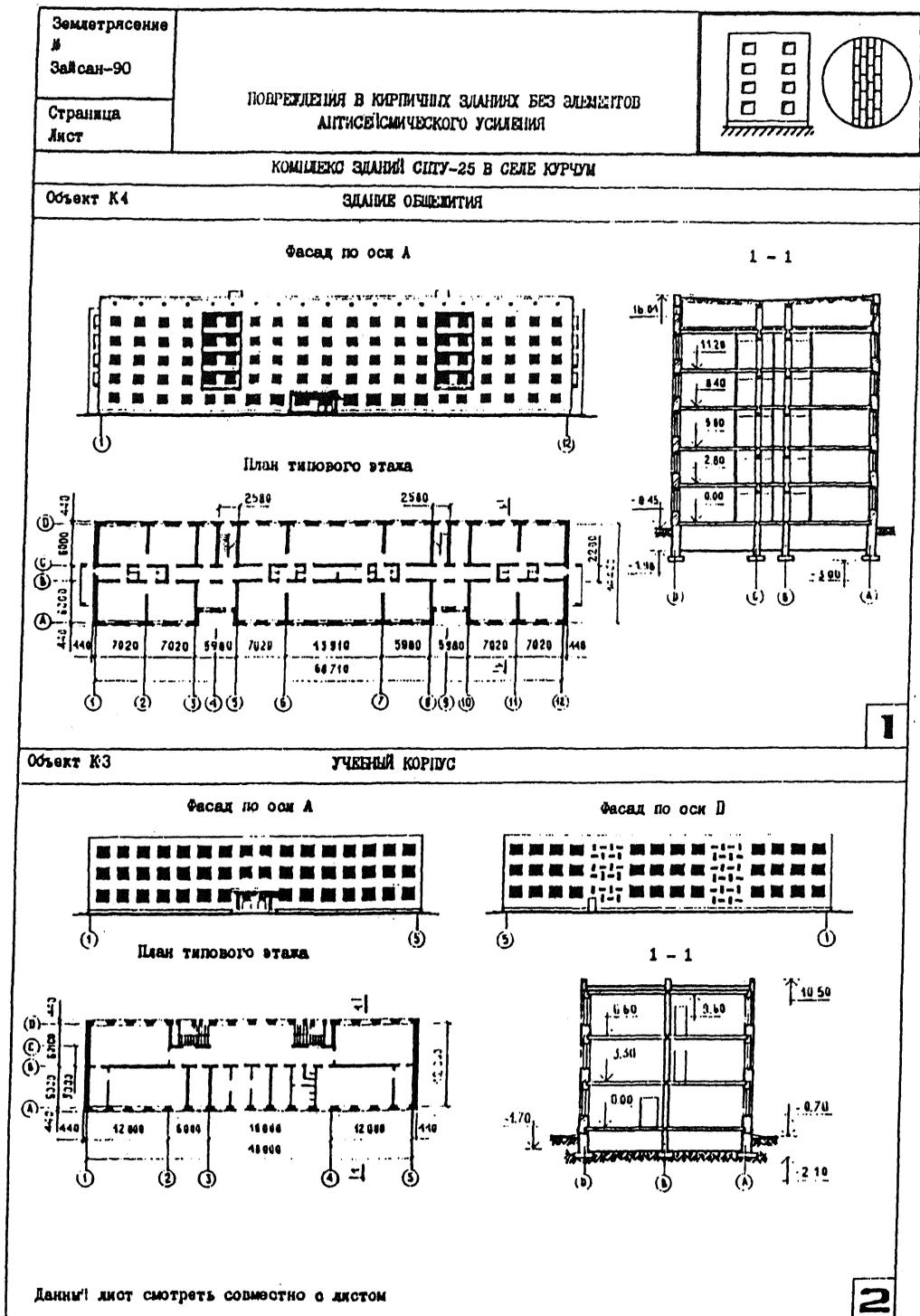


Figure 11

Figures 11 to 14. Examples of elaborated catalogue sheets (Taubaev et al. 1992)

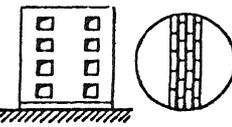
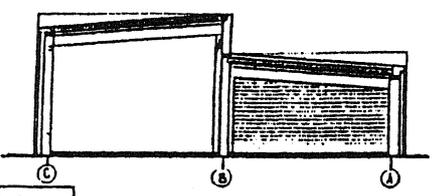
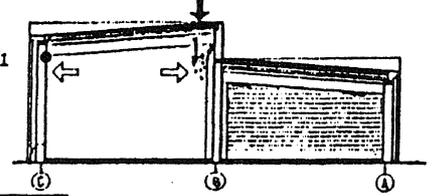
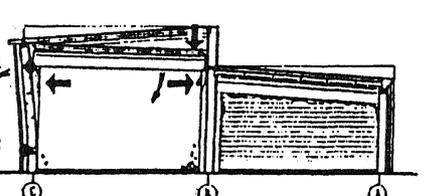
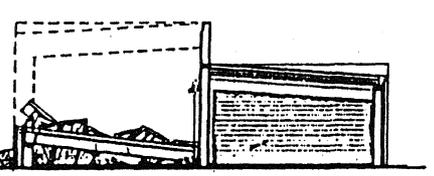
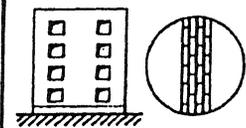
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| Землетрясение № Зайсан-90 | ПОВРЕЖДЕНИЯ В КИРПИЧНЫХ ЗДАНИЯХ БЕЗ ЭЛЕМЕНТОВ АНТИСЕЙСМИЧЕСКОГО УСИЛЕНИЯ |  |
| Страница Лист | | Объект К7 УЧЕБНЫЕ МАСТЕРСКИЕ |
| Стадии развития разрушений | | Описание |
|  | <p>Стадия 1. В верхней части пиллестр стены по оси В образуются наклонные трещины под опорными бетонными подушками балок покрытия гаражей. Балки покрытия сохраняют устойчивое положение. Анкерные крепления опорных подушек перестают выполнять свои функции.</p> | |
| <p>St.1</p>  | <p>Стадия 2. Под действием вертикальной нагрузки от конструкции покрытия разрушается кирпичная кладка под опорными подушками, балка покрытия начинает перемещаться вниз с вращением относительно точки O_1. При перемещении балки, установленной наклонно, возникает усилие распора, воспринимаемые конструкциями стен по осям В и С.</p> | |
| <p>St.2</p>  | <p>Стадия 3. Перемещение балки вниз сопровождается срезом кирпичной кладки пиллестры стены по оси В. Величина усилий распора резко возрастает. На опоре В эти усилия воспринимаются стеной с включением в работу поперечной перегородки (на схеме перегородка заштрихована). Пиллестра стены по оси С не способна воспринять усилия распора и в нижней её части образуются трещины в кладке. Кирпичная пиллестра начинает перемещаться, вращаясь вокруг точки O_2.</p> | |
| <p>St.3</p>  | <p>Стадия 4. Под действием комбинации вертикальной нагрузки и распорных усилий балка покрытия вместо с плитами покрытия обрушивается. Одновременно обрушается пиллестра стены по оси С. При землетрясении 14.06.90 г. процесс разрушения завершился примерно за 15 секунд.</p> | |
| <p>St.4</p> | | |

Figure 12

Землетрясение

Зайсан-90
Страница
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ПОВРЕЖДЕНИЯ В КИРПИЧНЫХ ЗДАНИЯХ



ПОВРЕЖДАЕМОСТЬ ЗДАНИЙ ШКОЛ В ЗАВИСИМОСТИ ОТ ОБЪЕМО-ПЛАНИРОВОЧНОГО РЕШЕНИЯ

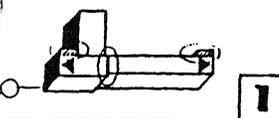
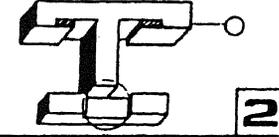
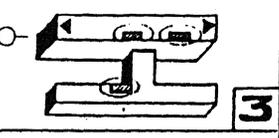
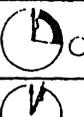
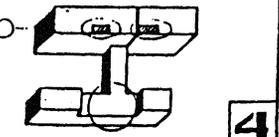
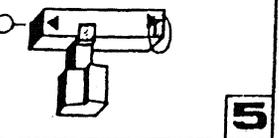
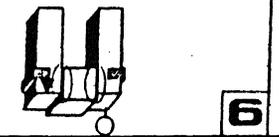
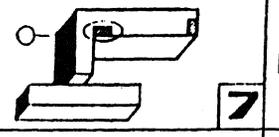
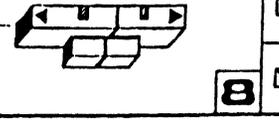
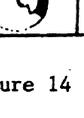
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Figure 14