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EVALUATION AND STRENGTHENING OF PUBLIC BUILDINGS AFTER THE KAMASHI (UZBEKISTAN) EARTHQUAKES IN 2000 AND 2001

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SUMMARY

This article concerns the documentation and evaluation of the local building fabric in seismically exposed areas, particularly in rural areas of central Asia. A characterization of certain construction types is made in regard to their earthquake behavior and on the basis of data collected during field surveys. The effectiveness of simple strengthening measures are then presented and analyzed. A developed evaluation tool is presented and its applicability is proven by a sample evaluation of two regional school buildings.

INTRODUCTION

The region of Uzbekistan in central Asia belongs to some of the highest seismicity areas of the world. In the last century, the catastrophic earthquakes in Taschkent (1966) and Gazli (1976, 1984) became infamous. In 2000 and 2001, the Kamashi area was struck by two earthquakes of rather moderate intensity (both had magnitudes of 5.4), causing heavy damage. The extent of the damage can be attributed to the high vulnerability of existing buildings that were constructed in traditional fashion and in wide-spread mountainous regions of the country. After the earthquakes, comprehensive retrofitting programs were initiated by the government and local authorities.

This paper is related to the project *Increasing of the Earthquake Safety of Residential and School Buildings from local Materials in Kamashi District, Uzbekistan*, supported by the German Committee for Prevention of Catastrophes (DKKV), and coordinated by the Bauhaus-University Weimar in cooperation with UzLITTII Taschkent and other institutions. The project in its initial stages was concentrated on documenting traditional, residential buildings that were built with the masonry of materials available locally, the classification of vulnerability according to the principles of European Macroseismic Scale EMS-98, and the development of simple measures, appropriate systems, and strengthening techniques to increase the earthquake resistance. One purpose was to introduce new systems and prototypes also applicable to other regions.

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To evaluate the structural solutions a specific PC-based tool was developed that enables one to check a building within three levels [1]:

Level 1: Structural parameters (opening structure, length and thickness of walls, etc.) indicating design deficiencies and critical building zones are considered.
Level 2: Torsional resistance, expressed by force amplification factors for the structural wall elements, is evaluated.
Level 3: Critical loads and deformation using capacity curves are determined.

These evaluation levels were applied to existing schools and will be applied to those to be developed.

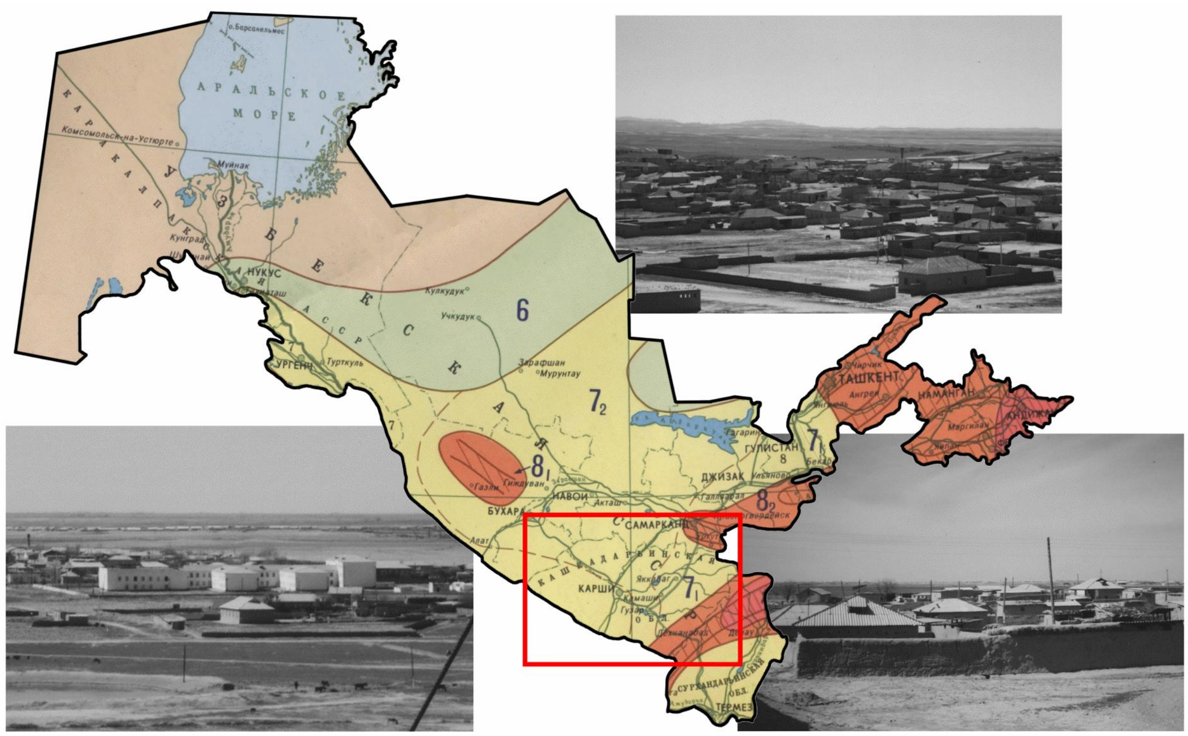


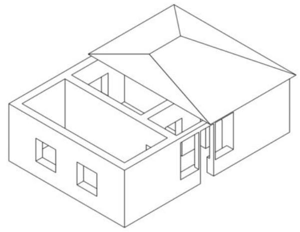
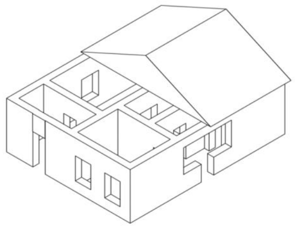
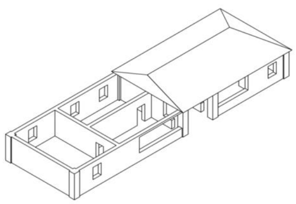
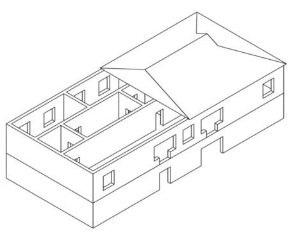
Figure 1. Seismic zone map [2] and impressions of a rural urbanization in Uzbekistan [3].

DOCUMENTATION OF REGIONAL BUILDING TYPES AT THE KAMASHI DISTRICT

The first step was to document the main building structures in a seismically exposed area, such as the *Kashkadarya* region in the southeast of Uzbekistan. The documentation shows that three building constructions predominate: clay structures (*Pakhsa*), unreinforced masonry, and, more rarely, buildings with confined masonry. In mountainous regions (the *Dekanabad* region, for example), private buildings are usually field stone houses.

Table 1 shows an extract with documentation of the main building types, especially of private buildings. The table shows that local buildings in *Kashkadarya* region are characterized by poor ductility features, leading to a lower standard than that for masonry buildings in European earthquake regions.

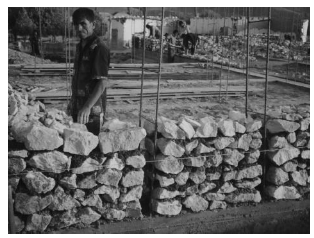
Table 1. Residential buildings of private housing [3] [4] [5].

Typical building types	Application	Vulnerability class EMS-98
adobe *(Pakhsa)*  	- private buildings (main building type in the *Kamashi* district)	A B C D E F probable range: vc A-B present state: vc A - materials with poor ductility features
rubble stone  	- private buildings (main building type in mountainous regions)	A B C D E F probable range: vc A present state: vc A - materials with poor ductility features - construction below standard
unreinforced masonry  	- private buildings (building type mostly in urban areas) - public buildings (school buildings in rural areas with less than 2 floors)	A B C D E F probable range: vc A-C present state: vc AB - torsion effects - construction below standard
unreinforced masonry with RC floors  	- private buildings - public buildings (school buildings in urban areas with more than 2 floors)	A B C D E F probable range: vc B-D present state: vc B - soft story - construction below standard

The typical structures are evaluated according to the principles of European Macroseismic Scale EMS-98, which means that traditional, regional building types are classified on the lower border to the EMS scale in regard to their construction and material features.

The problem with this evaluation is that the EMS-98 scale does not distinguish between main building constructions concerning quality of the building or possible reinforcement measures applied to the building. Because of this, the second step compares scaled construction and reinforced buildings regarding their probable earthquake ratios. On this basis reinforced construction can also be classified according to the EMS-98 scale and the improvement to main construction can be shown.

Table 2. Evaluation of strengthened systems [3] [4] [6].

<table>
<tr><th>Present state</th><th colspan="2">Applied strengthening techniques</th><th>Vulnerability class EMS-98</th></tr>
<tr><td colspan="3">adobe (Pakhsa)</td><td rowspan="2">A B C D E F
probable range: vc A-B
present state: vc A
strengthened: vc A
- only few improvement to present state (material, ductility)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">rubble stone</td><td rowspan="2">A B C D E F
probable range: vc A
present state: vc A
strengthened: vc AB
- improvement due to higher ductility features
- change of construction type</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">unreinforced masonry (example: school building)</td><td rowspan="2">A B C D E F
probable range: vc A-C
present state: vc AB
strengthened: vc BC
- improvement with regard to the strengthening technique</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">unreinforced masonry with RC floors (example: school building)</td><td rowspan="2">A B C D E F
probable range: vc B-D
present state: vc B
strengthened: vc C
- increase of the ductility due to RC frame system and an earthquake resistant design</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

The reinforcement measures based upon a strengthening system developed by Dr. S.A. Khakimov (UzLITTI Tashkent) were applied especially to traditional adobe or masonry constructions in areas with a low level of infrastructure.

REPRESENTATIVE PUBLIC BUILDINGS OF THE REGION

The main interest for evaluating public buildings is on schools and kindergartens. A particularly high priority should be put on the rise of earthquake resistance for these buildings. The collapse of one or several school buildings as a result of an earthquake during school hours would have disastrous effects on the affected place or region, as a large number of victims would be expected.

During two earthquakes (20/04/2000 M=5.4, 18/01/2001 M=5.3) in the *Kashkadarya* region nearly all school buildings were heavily damaged. The biggest damage appeared on buildings established in the traditional *Pakhsa* construction. All schools of this type were immediately removed and rebuilt with a higher level of earthquake resistant design.

Today, school buildings in this region basically follow only two construction types:

- brick masonry (either strengthened or not)
- stone masonry (either strengthened or not)

The presentation of the evaluation method should take place on the basis of two representative school buildings from the region:

1) Public School *Ainakul*

The school was built in the middle of the 1980's in the village of *Ainakul* located in a region of Uzbekistan called *Kashkadarya*. It consists of five blocks which are separated by joints of each other (Figure 3). Blocks 2, 3 and 4 accommodate the classrooms. Block 1 is a passage that connects all other blocks with each other. In Block 5 there are a gym and a dining room. The whole complex of buildings has two floors except for Block 2, which has 3 floors. For the following evaluation of the school, only Block 2 (Figure 2) is examined. The walls of Block 2 are made of brick masonry and the floors are made of concrete.

Figure 2. Block 2 – Public School *Ainakul*[3].

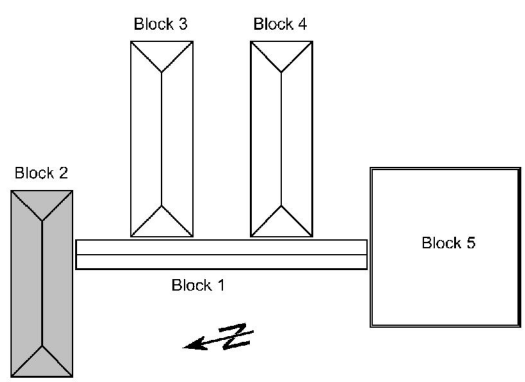


Figure 3. Plan – Public School *Ainaku.l*

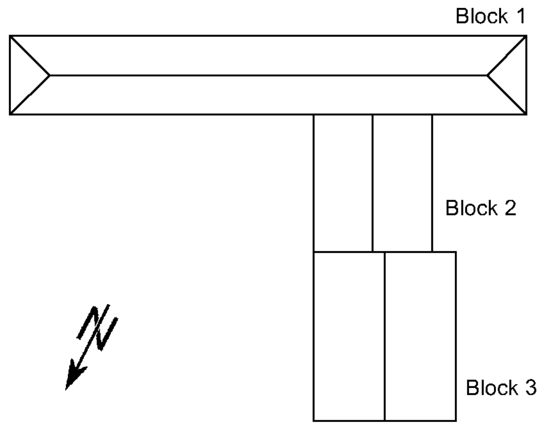


Figure 4. Block 1 - Secondary School *Kurchum*[7]. **Figure 5.** Plan - Secondary School *Kurchum.*

2) Secondary School *Kurchum* [7]

Block 1 of this school was built in 1963 in *Kurchum*, Kazakhstan. Block 2 and 3 were added later in 1982. Classrooms are located in Block 1. Block 3 contains the gym and the assembly hall of the school. In Block 2 the entrance area connects both of the other blocks. The whole school building was constructed with brick masonry. The floors in Block 1 are made of concrete. Since all blocks are connected with each other and are not separated by joints, all three blocks must be examined together for the evaluation.

EVALUATION OF EARTHQUAKE RESISTANCE OF MASONRY BUILDINGS

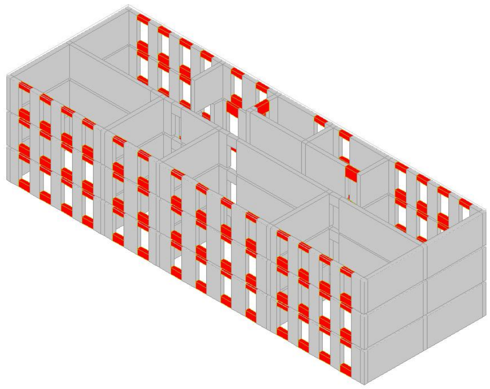
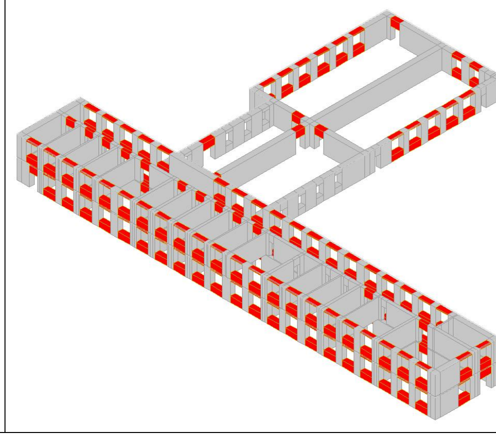
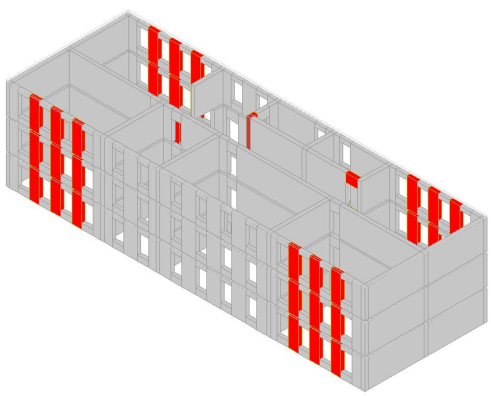
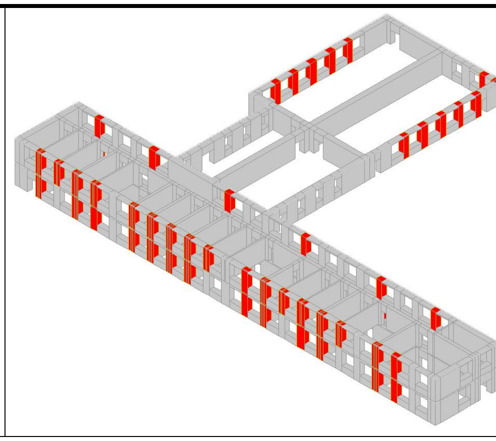
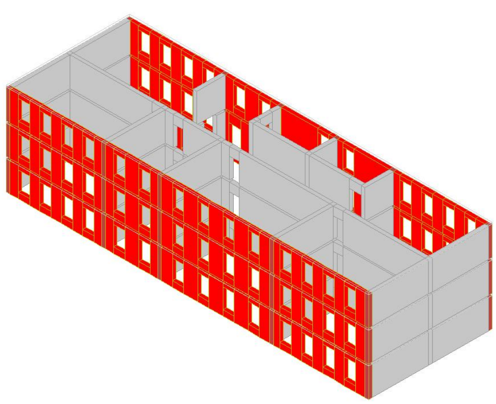
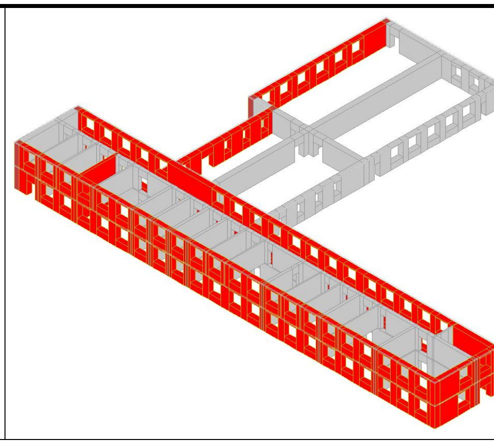
Evaluation of the sample buildings using the tool BLM [1]
BLM was developed to execute a fast evaluation for the earthquake resistance of loam and brick-work buildings. To evaluate a building, all stories with material parameters, opening structures, and vertical weights must be entered into the tool BLM at the beginning. A reading of the ground plan in the DXF format is possible. The modeling of the building takes only a few minutes. If a model of the building is constructed, it can be evaluated immediately. The evaluation process is divided into three categories: Constructive Parameters, Torsion Analysis, and Capacity Analysis. The algorithm used for the capacity analysis is based on the Ph.d. thesis of Lang [8].

All figures in Tables 3-6 are captured screen pictures from the tool BLM.

Level 1: Constructive Parameters
The following criteria are examined in the evaluation of the constructive parameters of the building:

- deviation of rectangular shape
- absolute building height and number of stories
- width and height of the openings
- width of the pillars between the openings
- width of the walls
- ratio of opening surface to the whole wall surface
- mass and stiffness distribution over the building height

Table 3. Evaluation of constructive parameters (Level 1).

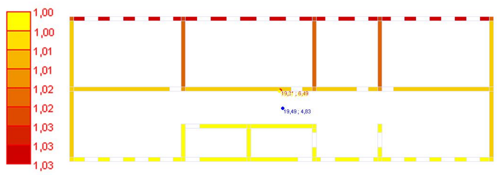
main parameter	Public School *Ainakul*	Secondary School *Kurchum*
width of the openings		
	The marked elements are windows that were too wide for the construction type used. Nearly all windows of both schools are too wide.	
width of the pillars between the openings		
	All pillars that are too narrow are marked in these figures.	
ratio of opening surface to the whole wall surface		
	These figures show marked walls that have an opening surface equal to or greater than 30% of the whole wall surface. Walls with wide windows and narrow pillars do not satisfy this criterion. These walls are typical for school buildings, because the wide windows are needed to properly light the classrooms.	

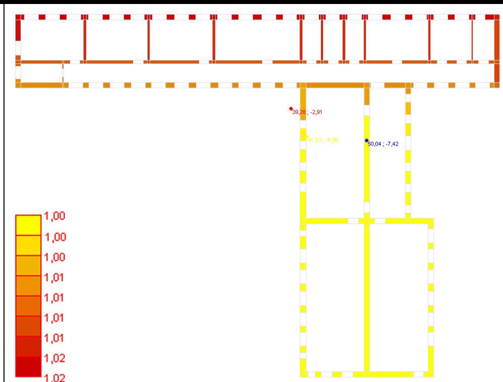
For a potential user the possibility exists to define the criteria for his own purposes. After the evaluation, those elements of the building are marked which have not satisfied the criteria defined above. The evaluation results of the separate parameters are stored and added to the overall evaluation result of the building.

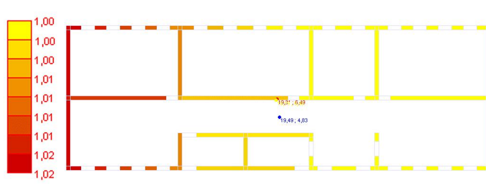
Level 2: Torsion Analysis

In this category the regularity and symmetry of the ground plan is examined. The tool BLM calculates the center of gravity and the center of stiffness for each story of a building. When a horizontal load (e.g. earthquake) acts on the building, it impacts on the center of gravity, while the building rotates around its center of stiffness. The greater the distance between both points, the larger the torsion effects.

Table 4. Evaluation of torsion vulnerability (Level 2).

<table>
<tr><th>main parameter</th><th>Public School Ainakul</th><th>Secondary School Kurchum</th></tr>
<tr><td rowspan="2">additional torsion-dependent wall load due to load impact in x-direction</td><td>


</td><td>


</td></tr>
<tr><td>This building is nearly symmetric in both directions. The red (darker) shaded areas show zones where additional wall loads accrue. Because of the symmetry the maximum amount of addition load is about 3% and therefore negligible.</td><td>Because of the absence of joints, the blocks of this building must be examined together. The ground plan of the building is L-shaped and vulnerable to torsion effects. Nevertheless, the maximum amount of additional load is only about 2% in the x-direction and therefore negligible.</td></tr>
<tr><td rowspan="2">additional torsion-dependent wall load due to load impact in y-direction</td><td>


</td><td>


</td></tr>
<tr><td>The maximum amount of additional load in this direction is about 2% and therefore also negligible. This building is incapable of experiencing torsion effects.</td><td>The load impact in y-direction shows the disadvantage of the L-shaped ground plan. The max. amount of additional load rises up to >300% in the eastern part of Block 1. This will cause higher damage in this building part.</td></tr>
</table>

In case of an irregular and asymmetrical ground plan or a ground plan with an irregular stiffness distribution, zones with torsion-dependent overloads accrue as a result of horizontal load impact. These zones are emphasized in color: the degree of the additional load is determined. This examination can be carried out for every story as well as for loads in the x- and y-direction.

Level 3: Capacity Analysis

In this evaluation category, the damage grade for the building is determined according to EMS-98 in dependence on an eligible seismic event. The calculation of the damage grades takes place with the help of a push-over analysis. The determined damage grade forms the basis of the overall evaluation of the building.

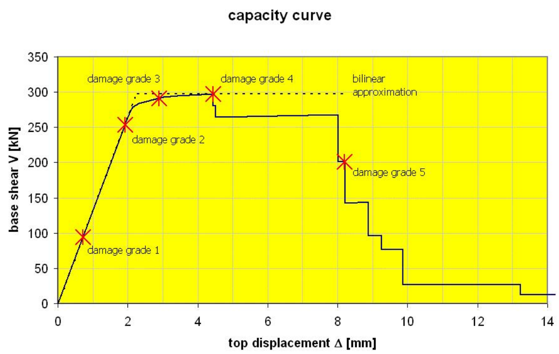


Figure 6. Capacity curve diagram.

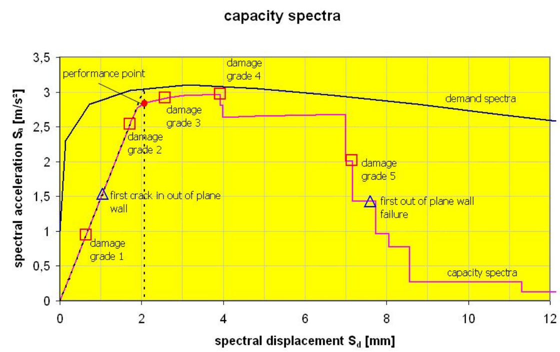
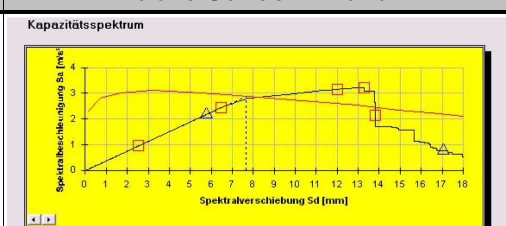
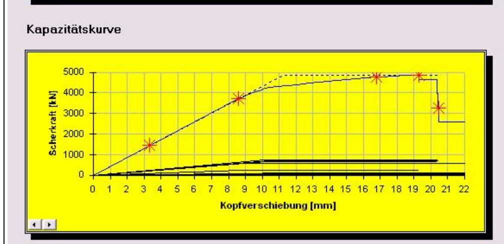
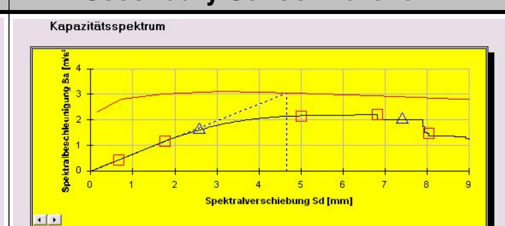
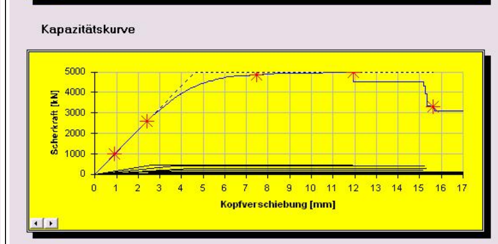


Figure 7. Capacity spectra diagram.

Figures 6 and 7 are schematic diagrams as created by BLM during the evaluation process. Figure 6 shows the capacity curve of a building for a chosen impact direction (x or y). The marks on the graph represent the different damage grades according to EMS-98. Figure 7 demonstrate the calculation of a damage grade using a demand spectrum and a capacity spectrum.

For this sample evaluation a demand spectrum in Uzbekistan's seismic code [9] was used as the seismic demand.

Table 5. Capacity analysis (Level 3).

main parameter	Public School *Ainakul*	Secondary School *Kurchum*
capacity analysis for load impact in x-direction	 	 
	For the chosen seismic event and a load impact in x-direction, the tool BLM calculated a damage grade of 2 according to EMS-98 for both schools.	

Level 1+2+3: overall evaluation
In the overall evaluation, results of the separate categories can be represented cumulatively. It is therefore possible to represent the extent and position of damages within the building caused by the chosen seismic event.

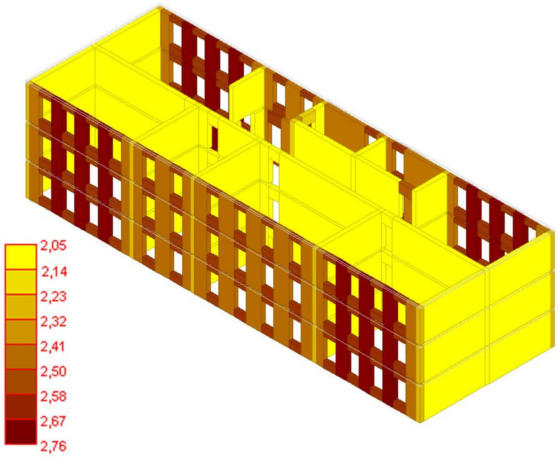


Figure 8. Overall evaluation – Public School *Ainakul.*

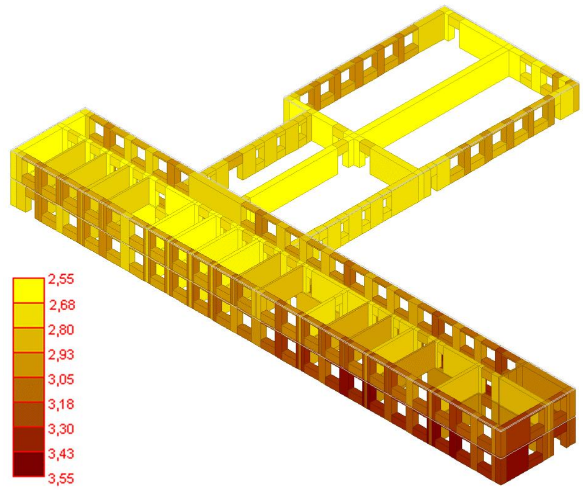


Figure 9. Overall evaluation - Secondary School *Kurchum.*

The red (darker) shaded areas show the most vulnerable parts of the building. The scale shows the grade of damage according to EMS-98 that is anticipated for the chosen seismic event and the part of the building under consideration.

RESULTS

Comparison between evaluation results and observed damage patterns

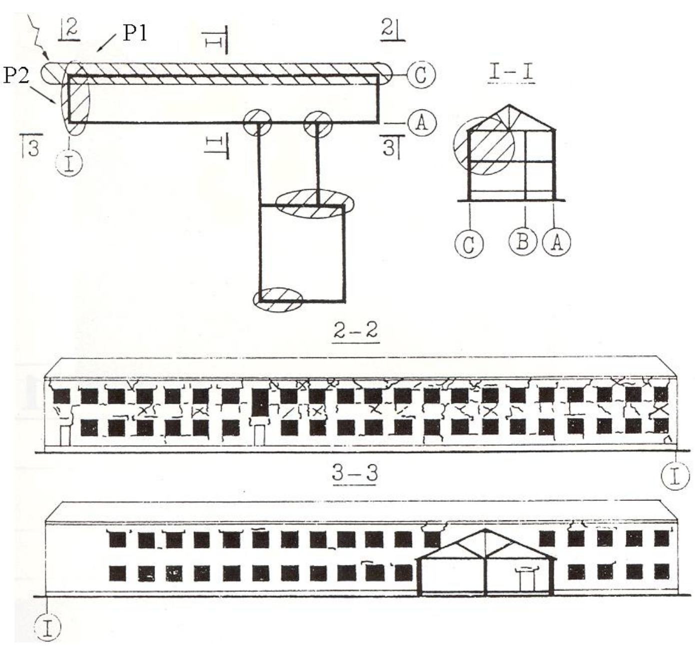


Figure 10. Documentation of observed damage – Secondary School *Kurchum* [7].

The Secondary School *Kurchum* was damaged during the *Zayzan* earthquakes of June and August 1990 (14/06/1990 M=6.9, 03/08/1990 M=6.3) in eastern Kazakh. The damage that occurred after these earthquakes is well documented (Figure 10).

Just as in the evaluation method, documentation on this topic also shows that the eastern part and the southern exterior wall of Block 1 are the most vulnerable areas of the building. The damage is a consequence of torsion effects due to the L-shaped ground plan and the wide openings. The damage at Block 3 consists of cracked and collapsed gable walls in the attic, which are neglected by the current version of the tool BLM. Figures 11 and 12 are pictures of the damaged eastern part of Block 1.

The comparison points out that the applied evaluation method is able to provide a good approximation of an observed damage pattern.

Figure 11. Eastern part of Block 1 - Secondary School *Kurchum* (P1) [7].

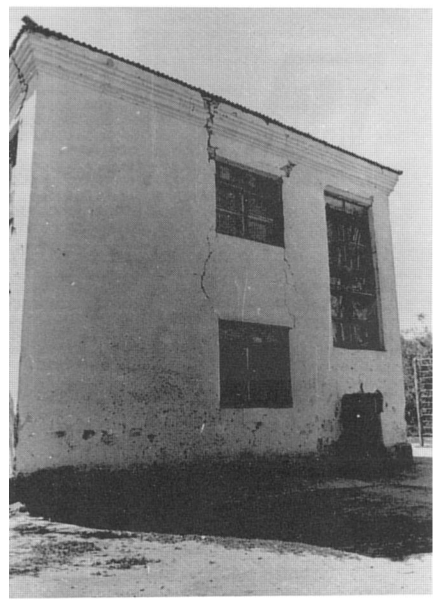


Figure 12. Eastern wall of gable on Block 1 - Secondary School *Kurchum* (P2) [7].

Damage prognosis and prevention

The overall evaluation results allow for the development of a damage pattern most likely to occur. In Figure 13, a damage pattern for the northern exterior wall of Block 2 of the Public School *Ainakul* is derived from the evaluation results (Figure 8).

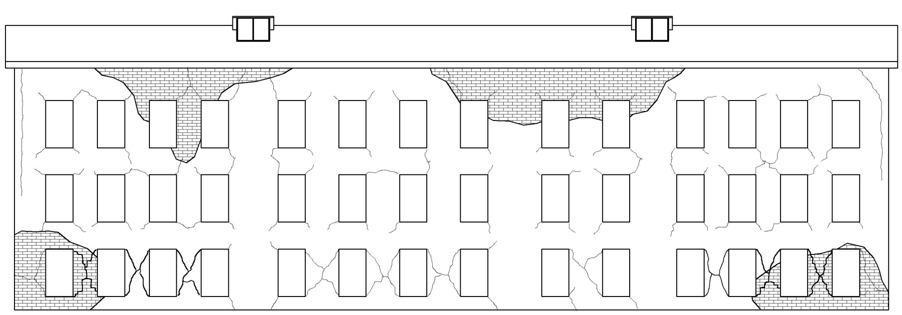


Figure 13. Predicted damage pattern – Public School *Ainakul* [1].

Local authorities may use such a predicted damage pattern to coordinate their approaches for strengthening buildings. A concentration on most vulnerable parts of the building and a cost minimization is thus possible.

The earthquake resistance of local dominant building types can be effectively improved by simple strengthening measures. These simple strengthening measures were used at several housing projects in the *Kashkadarya* region, especially for new and reconstructed public buildings. Essentially, two constructional strengthening methods are used for improving earthquake behavior.

Figure 14. Strengthening measures – ductile shells and steel enframed windows [4].

Figure 15. Confined masonry [6].

On the one hand, a continuous coupling of the walls takes place by means of reinforced concrete columns that reach from the foundation to the ceiling area. Foundation and ceiling areas are also made of reinforced concrete. Horizontally arranged reinforcement in the walls supports the concrete frame. In this way a confined masonry structure accrues. The openings are enframed with steel profiles.

The second constructional strengthening method insists in creating ductile shells inside and outside of all load-bearing walls. The shells are coupled by additional horizontal reinforcement.

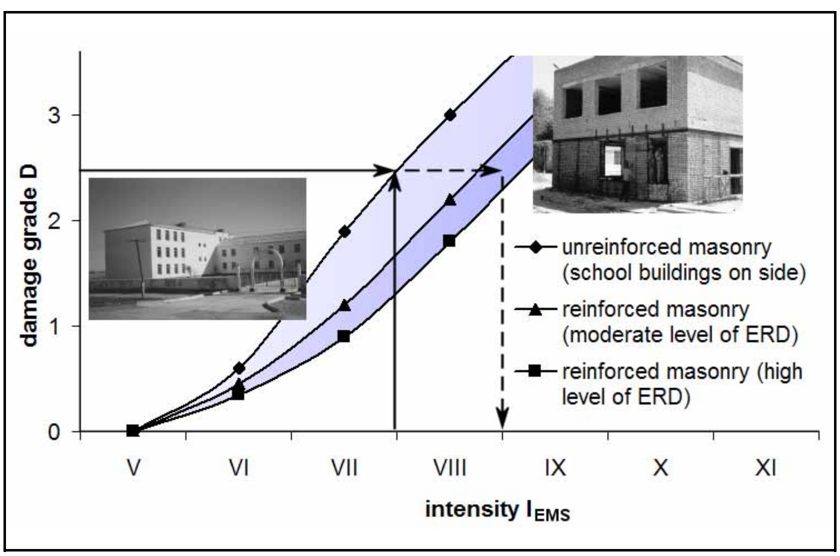


Figure 16. Improvement of earthquake resistance to applied strengthening techniques.

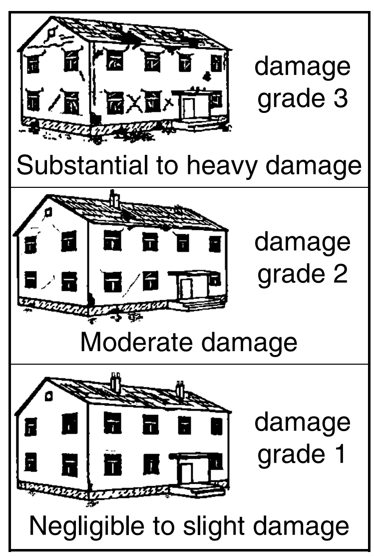


Figure 17. Damage grades according to EMS-98 [10].

By combining the previously addressed strengthening measures, an improvement on the earthquake behavior as shown in Table 2 can be reached. A traditional school building which is designed for an earthquake intensity of I=7 (EMS) can be improved by simple strengthening measures to the degree that an equivalent earthquake resistance can be expected for an earthquake intensity of I=8 (EMS). Figure 16 shows the range of improved earthquake resistance in dependence on different intensities that can be expected for reinforced construction. As a basis, the average damage degree according to EMS-98 expected for the whole construction is used.

CONCLUSION

Weak points within an existing or planned construction can be defined and analyzed by the tool BLM. Appropriate reconstruction and amplification measures can then be acquired on this basis. By the combination of analytical and empirical evaluation criteria, the improvement to the initial state of the construction due to strengthening strategies can be clarified.

After a comparison of such diverse criteria as the infrastructure in both regions, economic, climatic, demographic, and civil engineering reasons, these simple strengthening strategies can be assigned to local buildings of other regions with respective criteria (for example, the region of K*ashkadarya,* Uzbekistan to the region of *Turkestan*, Afghanistan).

Increasing globalization and the simultaneous rise in natural catastrophes in areas of growing population places an extreme amount of importance on this topic (cf. the Bam, Iran, earthquake on December 26, 2003).

The aim of future research is to integrate analytical evaluation results for a few building into an empirical seismic risk evaluation for macro-scale examination areas, and thus to refine the evaluation results.

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