A system for interdisciplinary assessment of earthquake effects on buildings and infrastructures

C.S. Dragomir
The National Research and Development Institute URBAN-INCERC, European Center for Buildings Rehabilitation, ECBR & U.A.S.V.M., Faculty of Land Reclamation and Environmental Engineering, Bucharest, Romania

E.S. Georgescu & I.S. Borcia
The National Research and Development Institute URBAN-INCERC & European Center for Buildings Rehabilitation, ECBR, Bucharest, Romania

SUMMARY:
Great Vrancea earthquakes occur every few decades, and approximately 60% of Romanian territory, mostly the S-E area, is directly affected. Therefore, the investigation requires a great effort and it should be prepared in advance, because loss of data concerning the earthquakes effects would be irrecoverable. A system for interdisciplinary assessment was taken into account for strong Vrancea intermediate earthquakes, but it will be useful also for crustal earthquakes of local or regional extent. Interdisciplinarity is given in the proposed theme that involves many logistical and human resources in areas such as earthquake engineering, seismology, geotechnical engineering, geodesy, economy, IT. The proposed system envisages a coordination centre and a clearinghouse at Bucharest, in NIRD URBAN-INCERC that coordinates branches of the territory (Iasi, Timisoara and Cluj). Given the extensive area, the system will pursue the establishment of regional centres and cities of Brasov and Constanta, where there are universities in this field.

Keywords: Vrancea earthquake, clearinghouse, regional centres, database

1. INTRODUCTION

The specific situation of seismic zones in Romania differs from other countries, because several categories of earthquakes (shallow, crusted - called normal - focal depth between 5 and 30 km, intermediate focal depth between 70 and 170 ... 200 km) are active in the territory. The most powerful and affecting a wide area are the intermediate type earthquakes located at the bend of the Carpathians, in Vrancea area, which is considered now a paleo-subduction process, with fractures of the tectonic plates in contact at different depths.

In Romania, the seismic zones exposed to Vrancea earthquakes are over 50% and the ones exposed to crusted earthquakes (shallow) approx. 15%. Statistics data on the seismic zones distribution of the urban population shows that approx. 35% of the total population, i.e. over 66% of the country's urban population is exposed to Vrancea earthquakes in urban areas.

The Regulation on the prevention and management of specific emergency risk from earthquakes and / or landslides, established by Ministerial Committee held at the Ministry of Regional Development and Tourism - MRDT, in case of destructive events requires notes, operative reports and evaluation reports intervention, for NSESM (National System of Emergency Situations Management) computer system. They are the basis for applying the immediate intervention measures according to Methodology on emergency assessment of building safety after earthquake and establish of intervention solutions and the seismic risk reduction measures under Ordinance no. 20/1994, for technical expertise and strengthening projects (****, 2005), (ME-003, 2007) and (****, 1994).

MRDT is part of NSESM and although MRDT's main responsibility regulation, is a special case of central public institution without decentralized units in the territory where the buildings are affected by

seismic impact. Meanwhile, after the 1977 earthquake, there are only few design institutes in the territory, although smaller design offices exist.

Because in Romania the major Vrancea earthquakes have features practically unique in the world and they occur every few decades and the affected area is very large, the investigation requires special effort and the data loss regarding the effects would be irrecoverable. In conclusion, Romania and MRDT cannot afford to lose field data observations and must be correlated with those from instrumental records. For these reasons, it is necessary to organize a specific system of effects investigation.

2. STRUCTURE OF ASSESSMENT SYSTEM

To establish an interdisciplinary research field system and with advanced informational techniques on the effects on buildings with different functions, in emergency situations caused by strong earthquakes, we studied data from EU countries and USA, New Zealand and Japan.

As a consequence, a command centre and clearinghouse database type at INCERC was suggested and a link between this centre and the territory shall be created (see Fig. 1).

Problems that appear in case of a Vrancea earthquake have unique character primarily due to the large surface area to be affected. Therefore, the structure of the institution that will conduct the interdisciplinary investigation field must be based on regional centres where specialists must be trained to lead the investigation to be carried out following an earthquake.

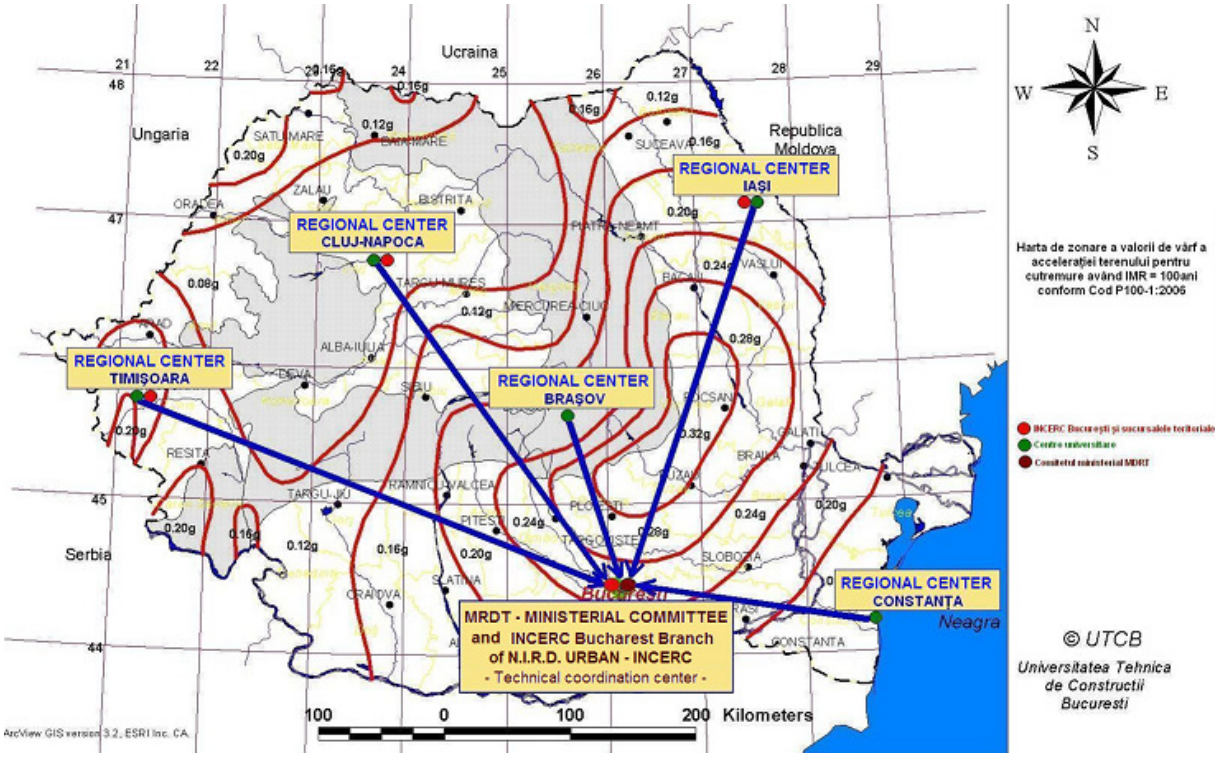

Figure 1. Territorial structure of post-seismic assessment system

Regulation, organization, coordination, implementation and control of legal and administrative actions and measures for post-earthquake investigation is going to be done, centrally, at the Emergency Situations Ministerial Committee, held by the Ministry of Regional Development and Tourism. At local level, investigation co-ordination will be made by the regional centres which will be ready by early cooperation under MRDT - Ministerial Committee and GIES (General Inspectorate for

Emergency Situations) - National Committee, in the five municipalities: Iasi, Timisoara, Cluj, Brasov and Constanta, activated if necessary (see Fig. 2).

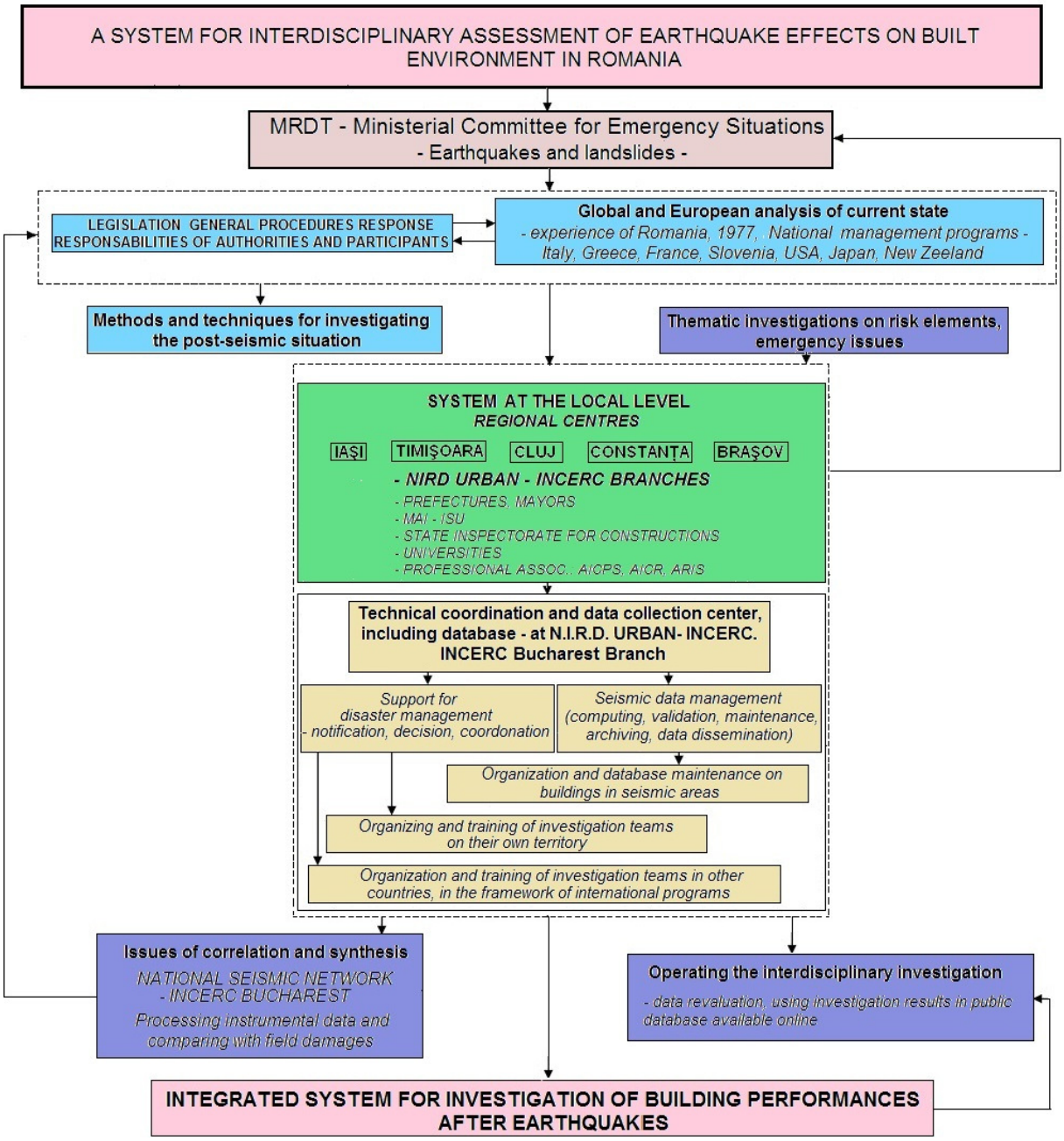

Figure 2. Organisation and functioning scheme of assessment system

To carry out the buildings post-seismic investigation activities should be taken the fallowing measures:

- To ensure systems and computer networks, with necessary peripherals (scanners, plotters, printers) for each of the regional centres;
- To prepare and implement at regional centres the computerized systems and databases for primary data storage from early buildings investigation, post-seism respectively, by surveyors and engineers;
- To ensure the introduction and transmission of computerized data from the investigation forms to the informational centre and database from INCERC Bucharest;
- To record in the database the data from early studies and teams of specialists working on the field after earthquakes.

Regional centres should provide an early distribution and a correlation of sending teams in different areas with technical staff available. Among specialists with special training and experience shall be held a committee at territorial centre to be responsible for technical guidance of the field teams and also to check daily reports and to go where the decision is difficult to be applied or complaints arise.

The core system is the INCERC Bucharest, which operates branches in areas: Iasi, Timisoara and Cluj. Given the extensive area to be affected by an earthquake, they will seek the creation of regional centres also in cities of Brasov and Constanta, where there are faculties in the civil engineering area. In addition to the informational centre from INCERC Bucharest, to create regional structure and its staff, the Prefectures/Municipalities, IES-Inspectorates for Emergency Situations, the State Inspectorate in Construction, University centres, ARIS (Romanian Asociation for Earthquake Engineering, AICR (Association of Civil Engineering in Romania) and AICPS (Association of Civil Engineering for Structure Design) will be envolved. Thus, the investigation team's members will be part of these institutions. For both the informational centre in Bucharest and regional centres an operation coordinator throughout the post-earthquake investigation will be assigned.

3. THEMATIC OF THE ASSESSMENT

We analyzed the thematic of the investigations regarding risk values, namely:
- Aspects of emergency / operational report on housing, damaged public buildings, infrastructure and utility networks, localities situation, effects on population, aspects of search and rescue operations in collapsed buildings;
- Issues that have implications for other legislations and sustainable developments: geological-geotechnical effects, ground-structure interaction, seismic network records, facilities and construction equipments, structural elements, furniture.

Emergency issues have emerged from analysis of collected data and measures taken in case of recent earthquakes. Such as the thematic request set result from the following topics:
- From practice of advanced countries like USA, Japan, Italy, Slovenia, Turkey;
- From Romanian experience at the earthquake of March 4, 1977 (Monograph of ICCPDC);
- From Regulation of the Ministerial Committee for emergency situations of MRDT;
- From the assessment and damage consolidation code P100-3, on which are made the buildings technical expertise reports (Code P100-3, 2008).

The data collected from strong earthquakes can be classified as:
- By purpose: usability on short-term; assessment of total economic losses or total funds needed for reconstruction; social impact assessment; prevention and emergency management; scientific proposals;
- By involved disciplines: geo-sciences; structural engineering, buildings and other built systems; social sciences, disaster medicine, economics;
- By period in which the data are collected and the detailed level. In developed countries, investigations last up to five years, so they valued the information in all areas of interest.

In order not to end up in the situation after 1977, when a number of valuable research data were lost by the authorities' decision to close those damages without a careful analysis of causes that contributed to their occurrence, data to be collected through investigation forms of the buildings, in generally, after the earthquake, were established. Thus, regarding post-seismic period within the data collection we will have:
- topics for the emergency investigation;
- topics for more detailed investigation, which may take months or even years, for example in the USA., the collection process of seismic data necessary for studies and research in earthquake engineering may take several years.

As reference documents there are EERI, FEMA guides, and ones used in the recent earthquakes (FEMA 178, 1992), (****, 1998) and (****, 1985).

Remediation and strengthening of damaged buildings by an earthquake aim to achieve their restoration for a normal exploitation and to ensure the resistance of each components and spatial stiffness of the building as a whole, when subjected to the seismic solicitations that will come. There are situations when some of the damaged buildings are proposed to be demolished. What is very important, and must be provided in a law is that, before proceeding to strengthen respectively, demolish the damaged buildings is necessary for teams to investigate the damages to be allowed to collect the data necessary in structural engineering studies.

According with Regulation of Ministerial Committee of MRDT the operative reports are transmitted every 12 hours since notification of specific emergency situation whenever the situation requires. Local committee's reports are submitted to permanent technical secretariats of county committee, Bucharest Committee respectively and last to the Permanent Technical Secretariat of the Ministerial Committee and to the Permanent Technical Secretariat of the National Committee.

Requirements from the Regulation of Ministerial Committee Annexes of MRDT regarding the framework Content of the operational report and content framework of the intervention evaluation report are highly concentrated in terms of earthquake engineering research and cannot provide data necessary for detailed studies in the field. Therefore, it is necessary that during the operations undertaken by teams of inspectors in the field, to be collected more detailed data for each category of construction, as was detailed in Chapter 3 of this Report.

Observations

1. Investigations thematic regarding elements of risk have to clarify how the data is collected for further statistical processing that may be made thereof.
2. The topics must be mentioned in the prefect orders issued post-seism, and with such a document the access of the investigation teams will be allowed on the field to collect the necessary data to explain the structural performance of buildings.
3. For civil engineering and public works the thematic will be detailed by specialists from the ministries (transport, roads, and dams) and specialized institutions.
4. Vulnerability analysis of buildings that have already suffered the impact of one or more earthquakes cannot be done without a database on the nature and extent of previous damages.

4. ASSESSMENT METHODS AND TECHNIQUES IN THE FIELD OF EARTHQUAKE EFFECTS

The investigation techniques used internationally were analyzed as it fallows:

– Investigation using satellite images, GIS technology, aerial video and instrumental recording techniques in the building before and after a destructive earthquake.

– Advanced techniques used to investigate damage of buildings after the earthquake, on the European Project STEP in 2008 to Bovec in Slovenia, in the exercises for the integrate use of the two methods of assessment (STEP inspection form and Italian inspection form AeDES), as to evaluate the possibility of international cooperation where after the destructive earthquakes experts opinion is needed.

Considering the studies conducted to establish the interdisciplinary investigation system on field and using advanced informational techniques regarding the effects on construction with different functions in emergency situations caused by earthquakes, the following are proposed:

– Technical coordination centre and the five regional centers should have the software used at international level for processing satellite/air images to detect areas with severe damage; thus the

technical teams within each territorial and coordination technical center should have satellite images made before the earthquake to be compared with those made after the event.

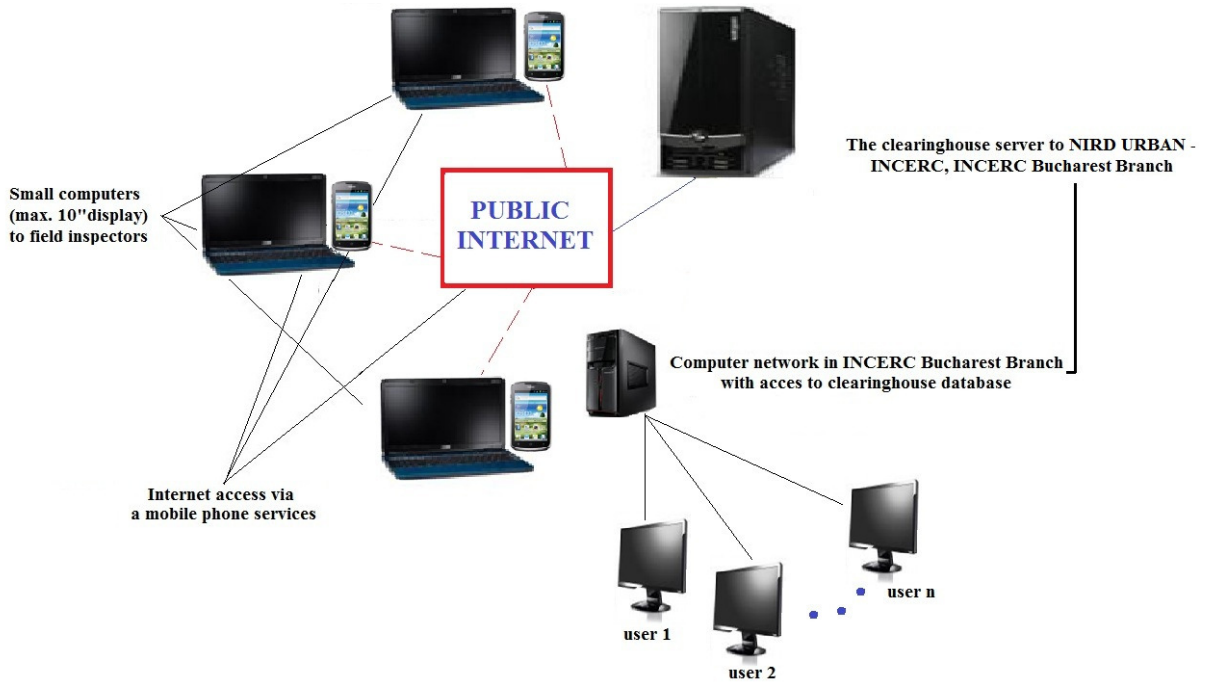

Figure 3. Method of transmitting data collected by inspector teams in the field to daily update the database

– The existence of an auto laboratory equipped with necessary equipments (sclerometer, pahometer, presses, ultrasonic devices to determine the mechanical characteristics of building materials, seismic instrumentation equipment, etc.), structural investigation having as model the mobile laboratory used in the inspection from Bovec, Slovenia (STEP, 2008);
– Create form stocks for inspection in each center and the existence of minicomputers for completing forms electronically. This method would help reduce the time required for intervention as well as a quick update of the existing data at technical coordination center of the Branch INCERC in case the data are transmitted through satellite (see Fig. 3).
– Creating a database of articles corresponding with fields from the forms used in the inspection that will contain data regarding the buildings investigation from 1977 and will be updated after each earthquake.

5. ASPECTS OF CORRELATION AND SYNTHESIS OF INSTRUMENTAL AND BUILDING DAMAGE DATA

• *Pre-seism inventory and data collection on initial state of built systems*. Have been proposed domains and modalities regarding how the fields will be pre-seismic inventories and will collect baseline data on built systems to be compared with the situation after the earthquake impact. For pre-seismic data collecting the requirements of national and international documents were taken into account for existing buildings assessment. From the analysis of these documents the data that can be collected in the first phase of the investigation has been extracted to create a database that contains existing buildings and their situation (FEMA 154, 2002), (FEMA 310, 1998) and (Code P100-3, 2008).

• *Instrumental seismic recording.* Accumulation of large numbers of data on the dynamic characteristics of different types of building, created the possibility of statistical interpretation of

experimental results. Data obtained before and after strong earthquakes in 1977 and 1986, allowed interesting statistical correlation between the degree of damage and increase of their periods. For INCERC station response spectra are known for 12 azimuth equidistant horizontal lines, for a fraction of critical damping of 5%, for events in 1977.03.04, 1986.08.30 and 1990.05.30. There are considerable differences in spectral composition from one event to another.

- *Dynamic measurements on buildings.* One of the measures that should be included in the methodology ME-003/2007 investigations is to correlate the results from the field and from processing seismic data obtained by seismic building instrumentation. Identifying the damage degree of buildings will be made by comparing the characteristics recorded in the database INCERC Bucharest branch for building types investigated, with the parameters registered after that event. One of the most reliable solutions to determine characteristics is using wireless sensors for recording response. Such devices can be placed inside the building and data acquisition can be done from the outside, no need for the inspector to remain a long time in the damaged building. Devices are currently present on the European market at affordable prices.

- *Cumulative vulnerability characteristics.* It is particularly important for earthquake engineering research in the goal of seismic risk reduction in Romania, to specify in the order no. 20/1994 as a part of the funds provided for rehabilitation and strengthening of representative structural building category to which they belong, to be directed to the acquisition of seismic instrumentation systems. In this way, representative buildings (or buildings that meet certain criteria on age, structural type, height, building area/performed) under first class of seismic risk, will be primarily investigated.

From seismic data recorded with these systems dynamic parameters will be determined in the initial state of buildings. So after consolidation and during building works dynamic measurements shall be done for an overall assessment to enhance the accuracy of chosen solution.

Besides the necessary measures to be taken by local authorities, under Article 10 of GEO no. 20/1994, a periodic review of geodynamic equipment will be ensured during and after intervention work, and after important seismic events for the collection of data recorded.

- *Post-seismic inspections.* Among lessons extracted from the earthquakes in New Zealand and Japan, to be noted the following points (EERI, 2011), (****, 2011):

– As many accelerograms record we have, we find that the acceleration potential is higher, the codes have changed.

– Long oscillation periods and other countries have become a hazard since building height is always growing, the risk must be controlled. On seismic events occurred in New Zealand is considered justified switching to IMR = 475 years in the Romanian Code seismic design of structures (Code P100-1, 2006).

– Applying a post-earthquake investigation, particularly rigorous in New Zealand, led in 2011 to block and also evacuate Christchurch's downtown.

– Scenarios which may include successive earthquakes are reliable as a predictive tool in managing emergencies.

Long periods are becoming a reality more often found, see Chile, 2010, New Zealand, 2010-2011, Japan, 2011, in countries with relatively dense seismic network. Safe design of future high buildings in Romania will depend largely on (Medina F., 2010), (EERI, 2011) and (****, 2011):

- Correct understanding and forecasting for displacement's trends of spectral peak periods over 1.2 s, through Code P100-1;
- Developing a map of the corner period T_{rec} for new areas suitable for increased magnitude and T_{rec} of greater than 100 years. Ensureing functioning of seismic network have to be a national interest in Romania.

After analyzing some aspects of construction from establishing of damage degree to building inspections after recent earthquakes in developed countries in terms of seismic protection, the question arises: *Is it necessary and feasible to develop a rapid method to determine dynamic characteristics before and after a major earthquake on which to decide the state of the structure*?

Appropriate response will depend both on certain theoretical developments and making a sufficient number of dynamic characteristic measurements on actual buildings, calibration being based on data before 1977 and after 1977, which will require further research.

6. RECOVERY DATA COLLECTED BY FIELD ASSESSMENT TEAMS– ON LINE PUBLIC DATA BASE

At NIRD URBAN - INCERC, INCERC Bucharest branch, the database SYS FIELD INV (interdisciplinary SYSthem of FIELD INVestigation with advanced technical information on building effects with different functions in emergencies caused by earthquakes) including data collected on field by inspector teams was elaborated (see Fig. 4).

By exploiting the software created by INCERC, users can obtain numerical values and graphics for all six buildings investigated by INCERC specialists that were in the L'Aquila area after the earthquake dated in 06.04.2009, in the framework of STEP Project.

In Excel tables all the data recorded in all six assessment forms were taken by two inspector's delegates by INCERC (DATABASE - data collection of investigation teams. xls) and the database in Access *SIS FIELD INV.mdb.*

For SIS FIELD INV.mdb database, tables are presented (imported from *DATABASE - data collection of investigation teams.xls*) and relationships between these tables. Also are presented the output data in reports form created in ACCESS (see Fig. 5).

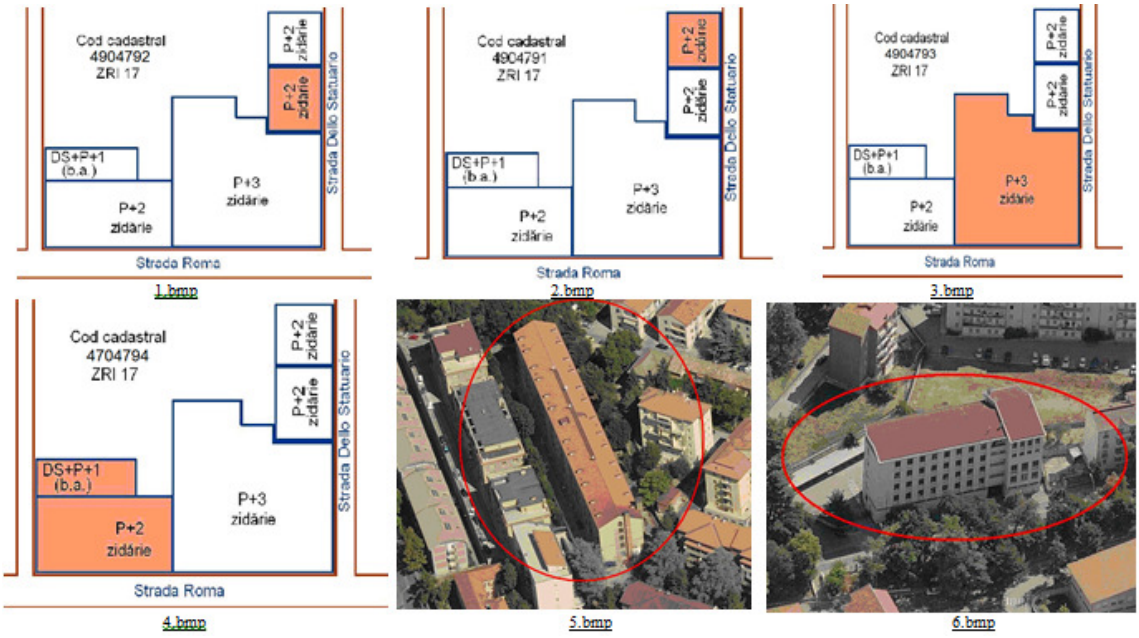

Figure 4. Input data: on damage of the six buildings investigated by INCERC inspector team in June, 2009, after L'Aquila earthquake in Italy.

Output data is presented as lists that contain data on investigated buildings using the following query:

– Buildings with reinforced concrete frame structure (RCFS) declared SAFE BUILDINGS (SB);

– Buildings with reinforced concrete frame structure (RCFS) declared UNSAFE BUILDINGS (UB);
– Masonry bearing wall buildings (MB) declared SAFE BUILDING (SB);
– Masonry bearing wall buildings (MB) declared UNSAFE BUILDINGS (UB);
– Individual dwellings (ID) declared UNSAFE BUILDINGS (UB);
– Public buildings (PB) wich a structure's evaluation was made (SEM).

Graphic representations containing sketches of buildings, inspectors scanned signatures, description of buildings, and general comments filled by inspectors in the inspection forms were used.

Virtual space thus created will have two sections, namely:
- A section of clearinghouse type where data from field investigation teams will be collected; also the information can be retrieve by authorized persons with access allowed based on codes;
- A section dedicated to public information; the public can access the site and may take possession of the information stored in databases constructed for this purpose. Reliance on information taken from the site is on the prestigious institution that operates under the coordination of MRDT, and has participated in inspections conducted after the 1977 earthquake.

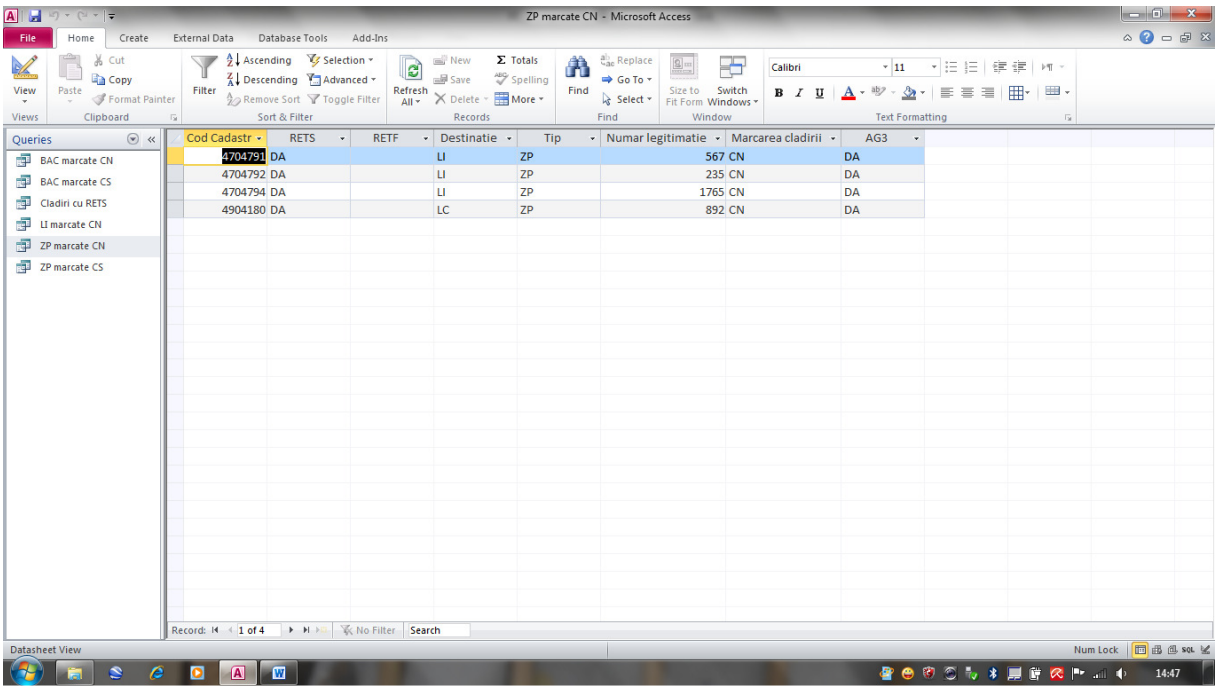

Figure 5. Example of date output : List of **M**asonry Bearing Wall **B**uildings type as **U**nsafe **B**uildings

The site of information center and database, as called for Pre-normative research, will be created so that any interested person can access and select information according to certain search parameters such as: building age, structure type, height, damage degree, etc.

During the inspection works databases will be updated so that the end of each inspection day to know the exact number of buildings inspected and the damage degree for each one.

7. CONCLUSION

Functioning mode of the system for assessment in emergencies caused by earthquakes and the structure of the data collected by the field teams that participated in post-earthquake inspection was presented in this paper. For this purpose the legal basis for operation of the assessment, specific requirements and the structure of proposed interdisciplinary assessment system were presented.

At INCD URBAN-INCERC, INCERC Bucharest Branch, was developed *SIS INV TEREN* database (interdisciplinary assessment system on the field with advanced informational techniques of effects on buildings with different functions in emergencies caused by earthquakes), which includes data field collected by the inspector teams.

By exploiting software created at INCERC, numerical values and graphics can be obtained for those six buildings investigated by INCERC inspectors that participated at the international assessment teams after the L'Aquila earthquake dated 06.04.2009.

It was proposed to analyze the need and desirability of promoting a normative act of type Ministerial Order or Government Decision to establish functioning and resources of interdisciplinary assessment system with advanced informational techniques of effects on buildings with different functions in emergencies caused by earthquakes, by the MRDT.

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