17WCEE 17th WORLD CONFERENCE ON EARTHQUAKE ENGINEERING

With Bosai / Disaster Management Expo in Sendai

At Sendai International Center, Sendai, Japan (Hybrid Conference)

Links

International Association for Earthquake Engineering

Japan Association for Earthquake Engineering

Proceedings

As the spread of the COVID-19 has become a problem around the world, many countries are facing health and economic issues. In addition, many of you are also being subjected to various restrictions in your daily life, as movements inside and outside of the country, and visits and meetings with other people are restricted. First of all, I would like to sincerely wish for the health of you, your family and colleagues, and for an early resolution of the COVID-19 problem.

As mentioned in previous communications, the 17th World Conference on Earthquake Engineering (17WCEE) was originally planned to be held from September 13 to 18, 2020, but due to the COVID-19 problem, we, the 17WCEE Organizing Committee, decided to postpone the 17WCEE by one year, to be held from September 27 to October 2, 2021, the 10th anniversary year of the 2011 Great East-Japan Earthquake and Tsunami Disaster in the same venue, in Sendai City, Miyagi Prefecture, Japan. At the same time, we promised that the full papers submitted by the end of March 2020 will be published as 2020 17WCEE Proceedings in September 2020.

I am very happy to inform you that delivering on this promise, the Proceedings has been successfully published this month with the support of all 17WCEE related people. The 17WCEE Organizing Committee would like to express sincere appreciation to those involved. The Proceedings contains over 2,500 full papers submitted by the end of March 2020 after completing all registration procedures by the deadline. Although the 17WCEE will be held in 2021, the papers published in the Proceedings become the author's research achievements in 2020 and can be widely referred to and utilized in the world.

Also, based on the one-year postponement of the conference, we will accept additional papers and combine them with the 2020 17WCEE Proceedings, and publish them in September 2021 as 2021 17WCEE Proceedings.

The 17WCEE Organizing Committee will do its best to successfully hold the 17WCEE in 2021.

Kimiro MEGURO
Chair, 17WCEE Organizing Committee
Professor, The University of Tokyo

Official Announce Letter is here.

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JAPAN ASSOCIATION FOR EARTHQUAKE ENGINEERING

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With Bosai / Disaster Management Expo in Sendai

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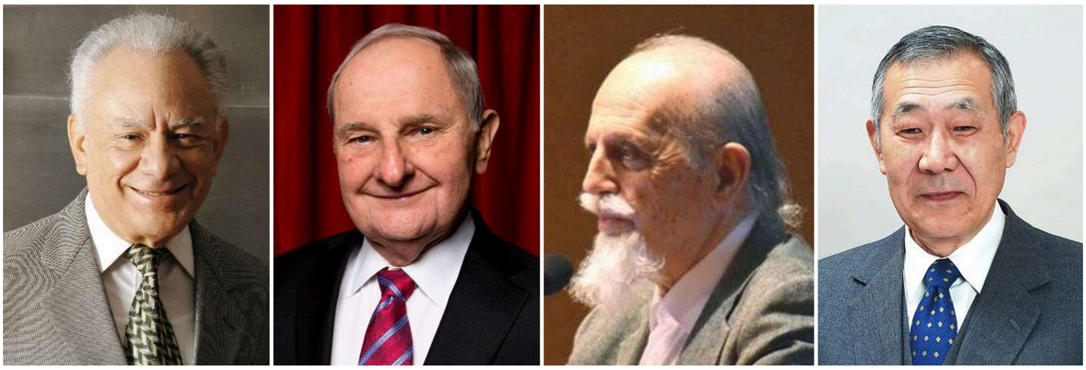
Program / Speakers

Meet the Masters | Keynote Lecture | Invited Lectures | Conference Style

Blind Prediction Contest | Future Direction | Social Program

Meet the Masters



In "Meet the Masters"organized by IAEE (International Association for Earthquake Engineering), we invite great names of earthquake engineering to WCEE. The four masters listed below are invited to 17WCEE. For each master, a special session related to the master’s expertise is organized during WCEE, in which the master offers a keynote lecture. To make the session run most smoothly, a person who has been close to the master is asked to serve as a moderator.

The Masters at the 17WCEE are:
*Prof. James Jirsa (USA)
*Prof. Tsuneo Katayama (Japan)
*Prof. Luis Esteva (Mexico)
*Prof. Theo Tassios (Greece)

Keynote Lectures

*The speakers and the lecture materials may change without prior notice.

Professor Kojiro Irikura

Professor

Aichi Institute of Technology, Japan

For more details

Professor Satoshi Fujita

Professor

Tokyo Denki University, Japan

For more details

Mr. Niels B. Holm-Nielsen

Practice Manager

Global Facility for Disaster Reduction and Recovery (GFDRR)

For more details

Dr. Robert J. Budnitz

Staff Scientist (retired)

Lawrence Berkeley National Laboratory, University of California, USA

For more details

Dr. Amod Mani Dixit

General Secretary

National Society for Earthquake Technology (NSET), Nepal

For more details

Professor Tracy Kijewski-Correa

Professor

The University of Notre Dame, USA

For more details

Invited Lectures

*The speakers and the lecture materials may change without prior notice.

Professor Xilin LU

Professor

Research Institute of Structural Engineering and Disaster Reduction, College of Civil Engineering, Tongji University, China

For more details

Professor Gregory G. Deierlein

John A Blume Professor of Engineering,

Stanford University, USA

For more details

Dr. Jun-ichi Hoshikuma

Center for Advanced Engineering Structural Assessment and Research, Public Works Research Institute, Japan

For more details

Professor Muneo Hori

Director General

Center for Mathematical Science and Advanced Technology, JAMSTEC, Japan

For more details

Professor Mustafa Erdik

Professor

Kandilli Observatory and Earthquake Research Institute, Bogazici University, Turkey

For more details

Professor Misko Cubrinovski

Professor

University of Canterbury, New Zealand

For more details

Professor Satoshi Yamada

Professor

The University of Tokyo, Japan

For more details

Professor Fabrizio Paolacci

Professor of Structural Engineering,

Roma Tre University, Italy

For more details

Conference Style

There have been some changes to the Presentation Style as follows.

1. Oral presenters who cannot attend the conference on-site can also make their presentation in real time by on-line.
2. For Poster Presentations, 17WCEE will not conduct an SOP (Short Oral Presentation) on-site, but instead, we are planning to hold SOP on-line (Flash Talk) in few minutes for each presentation. Additional information will be given

PROCEEDINGS OF THE SEVENTEENTH WORLD CONFERENCE ON EARTHQUAKE ENGINEERING
JAPAN 2021

Welcome

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HAN SEON LEE, HUILING PIAO, RUTH ALI ABEGAZ	EVALUATION OF ACCIDENTAL TORSION OF TORSIONALLY-BALANCED BUILDINGS USING THE RESISTANCE ECCENTRICITY
MASATO SAKURAI, TETSUYA NISHIDA	POST PEAK SIMULATION OF RC SHEAR WALLS WITH OPENINGS BASED ON NON-LINEAR FE ANALYSIS
JYOTI LAMSAL, KOICHI KUSUNOKI, MATSUTARO SEKI, TATSUYA AZUHATA	SEISMIC RETROFIT OF AN EXISTING RESIDENTIAL BUILDING IN NEPAL TO FUNCTIONALIZE AS A HOSPITAL USING FERROCEMENT
RYO INOUE, TAKURO MORI, KOTARO SUMIDA, HIROSHI ISODA, KEI TANAKA, TOSHIAKI SATO	STATUS OF WOODEN HOUSES IN MASHIKI TOWN TWO YEARS AFTER THE 2016 KUMAMOTO EARTHQUAKES
HOLGER LOVON, VITOR SILVA, ROMEU VICENTE, TIAGO FERREIRA	INCORPORATING EPISTEMIC AND ALEATORY UNCERTAINTIES IN FRAGILITY MODELLING OF MASONRY STRUCTURES
JOSEPH KUBIN, DANYAL KUBIN, UGURCAN OZCAMUR, ILKER ALI ILIS, GOKSENIN FEROGLU, BENGU ELCIK EROL, SELCAN KAAN ACAREL, MERVE YALCIN, OZGE YILDIRIM	SEISMIC ISOLATION OF A DATA CENTER BUILDING: HYBRID SYSTEM WITH CSS, LRB AND FVD
TED CROSS, FLAVIA DE LUCA, RAFFAELE DE RISI	VALIDATION OF MACRO-MODELLING AND EQUIVALENT FRAME METHODOLOGY WITH EXPERIMENTAL DATA
JOSEPH KUBIN, DANYAL KUBIN, GOKSENIN FEROGLU, HALUK SUCUOGLU, ILKER ALI ILIS, UGURCAN OZCAMUR, ILKER HAKKI OZDEM, SINEM YALCIN	RETROFITTING OF A BRIDGE FORM HISTORICAL STATION USING SEISMIC ISOLATION
GIUSEPPE ABBIATI, STEFANO MARELLI	SEQUENTIAL EXPERIMENTAL DESIGN OF HYBRID SIMULATIONS FOR BAYESIAN CALIBRATION OF COMPUTATIONAL SIMULATORS
AHSANA PARAMMAL VATTERI, DINA D'AYALA, PIERRE GEHL	BAYESIAN NETWORKS FOR SEISMIC VULNERABILITY ASSESSMENT OF CONFINED MASONRY SCHOOL SYSTEMS
LIDIJA KRSTEVSKA	SEISMIC TESTING OF NON-STRUCTURAL SYSTEMS
HAMOOD ALWASHALI, DEBASISH SEN, MASAKI MAEDA, MATSUTARO SEKI	ADVANTAGES AND LIMITATIONS OF RETROFITTING MASONRY INFILLED RC FRAMES BY FERRO-CEMENT BASED ON EXPERIMENTAL OBSERVATIONS
HAMOOD ALWASHALI, JINGYUE SUN, AHMED GHAZI ALJUHMANI, ALEKSEY SHEGAY, MASAKI	EXPERIMENTAL STUDY ON RESIDUAL SEISMIC CAPACITY OF RC SQUAT WALLS

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GIOVANNI MUCIACCIA, GIUSEPPE DI NUNZIO	CYCLIC BEHAVIOR OF SCREWED HEAD ANCHOR SYSTEM FOR APPLICATIONS IN NUCLEAR POWER PLANTS
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MANISH KUMAR, SUJIT V MATALE, DURGESH C RAI	INFLUENCE OF PERIMETER SUPPORTS ON THE SEISMIC RESPONSE OF PLASTERBOARD SUSPENDED CEILING SYSTEMS
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SIAMAK SATTAR, MIKE MAHONEY, RYAN KERSTING	FUNCTIONAL RECOVERY OF THE BUILT ENVIRONMENT AND CRITICAL INFRASTRUCTURE
ROHIT KUMAR ADHIKARI, DINA D'AYALA, ALASTAIR NORRIS	SEISMIC PERFORMANCE EVALUATION OF THE EXISTING AND RETROFITTED STONE MASONRY HOUSES IN NEPAL
DURGESH C RAI, PARUL SRIVASTAVA	SEISMIC FRAGILITY ANALYSIS OF C-BENT PIERS IN METRO VIADUCTS
FELIPE RIVERA, TIZIANA ROSSETTO, JOHN TWIGG	ASSESSING EARTHQUAKE RISK EVOLUTION FROM A PROCEDURAL JUSTICE PERSPECTIVE
AGUSTIN BERTERO, RAUL BERTERO, FILIP FILIPPOU	DEMAND-ORIENTED GROUND MOTION SELECTION USING NONLINEAR PREDICTORS OF RESPONSE
SERGIO LAGOMARSINO, STEFANIA DEGLI ABBATI, SERENA CATTARI	EFFECTS OF THE VERTICAL COMPONENT ON THE SEISMIC RESPONSE OF URM BUILDINGS
RICKY BAHERAMSJAH, ABDULBAR MANSOER, H HARINTO, HARI NURJAMAN, MASYHUR IRSYAM, M RIDWAN, L FAIZAL, H LATIEF, BINSAR HARIANDJA, SUWITO SUWITO, DWI DINARIANA	DEVELOPMENT OF EARTHQUAKE AND TSUNAMI DISASTER MITIGATION PLAN FOR MANDALIKA MOTOGP CIRCUIT IN LOMBOK
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SEBASTIAN CASTRO, FELIPE ARROSPIDE, ALAN POULOS, YOLANDA ALBERTO, JUAN CARLOS DE LA LLERA	CONSTRUCTION AND RISK EVALUATION OF A WATER SYSTEM NETWORK UNDER SEISMIC HAZARD IN CENTRAL CHILE
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VALENTINA PUTRINO, DINA D'AYALA	A MECHANICS-BASED PROCEDURE TO DETERMINE THE DAMAGE MECHANISM OF MASONRY WALLS SUBJECTED TO OUT-OF-PLANE HORIZONTAL LOADINGS
SERENA CATTARI, STEFANIA DEGLI ABBATI, SERGIO LAGOMARSINO	FLOOR SPECTRA VALIDATION THROUGH ACTUAL DATA FROM THE 2016/2017 EARTHQUAKE IN CENTRAL ITALY
SERENA CATTARI, DARIA OTTONELLI, FULVIO FRANCO, TOMMASO BUSCHIAZZO, ANDREA GUARDIANI	TOWARDS AN IMPROVED URBAN SEISMIC RESILIENCE: THE PILOT CASE STUDY OF SANREMO MUNICIPALITY
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CARLOS A ARTETA, ANDRES TORREGROZA, DANIEL GASPAR, NORMAN A ABRAHAMSON	HOW MANY CMS’ ARE ENOUGH FOR SEISMIC RESPONSE ASSESSMENT?
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ROBERT TREMBLAY, PAUL MOTTIER	A SIMPLE SELF-CENTERING BASE SHEAR FUSE FOR COST-EFFECTIVE CONTROLLED ROCKING STEEL BRACED FRAMES
AHMED ELGAMAL, ABDULLAH ALMUTAIRI, JINCHI LU	IMPLEMENTATION OF A MULTI-SPAN BRIDGE-GROUND PBEE FRAMEWORK FOR SEISMIC AND LIQUEFACTION SCENARIOS
MARIO LOPES, CARLOS SOUSA OLIVEIRA	EARTHQUAKE EARLY WARNING SYSTEM FOR PORTUGAL: FEASIBILITY AND PERSPECTIVE OF THE STAKEHOLDERS
KAZUMA INOUE, KEITA SAITOH, YUTA UMEYAMA, AKIRA IGARASHI, TAKAAKI IKEDA	ANALYSIS OF DIRECTIONALITY CONSIDERING PERIODIC CHARACTERISTICS FOR OVSERVED STRONG GROUND MOTIONS
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KHIN MYAT KYAW, KIMIRO MEGURO	NUMERICAL MODELING OF MID-RISE REINFORCED CONCRETE BUILDING INCORPORATION OF SOIL-STRUCTURE-INTERACTION FOR DIFFERENT SOIL CONDITIONS WITH AEM
HISASHI NAKAO, KOHEI EGUCHI, TOMOYA YONO, MICHIO OHSUMI	DAMAGE MECHANISM OF OKIRIHATA BRIDGE DUE TO KUMAMOTO EARTHQUAKE
MUNKHUNUR TOGTOKHBUYAN, TAGAWA HIROSHI, CHEN XINGCHEN	EXPERIMENTAL STUDY ON STEEL BEAM-TO-COLUMN JOINT STRENGTHENED BY BUCKLING-RESTRAINED KNEE BRACE USING STEEL BAR CORE
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MIGUEL MEDALLA, DIEGO LOPEZ-GARCIA, FARZIN ZAREIAN	SEISMIC CHARACTERIZATION OF STEEL BUILDINGS SUBJECTED TO MEGATHRUST EARTHQUAKES
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MASAKATSU MIYAJIMA, RYOSUKE NOGUCHI	INFLUENCE ON DAMAGE TO LIFELINE ON PERFORMANCE OF HOSPITALS IN THE 2018 HOKKAIDO IBURI-TOBU EARTHQUAKE IN JAPAN
KENJIRO YAMAMOTO, SHANTHANU RAJASEKHARAN, KIMIRO MEGURO	STUDY ON MOISTURE EFFECTS ON MASONRY RETROFITTED WITH FIBER REINFORCED PAINT
RUIFU ZHANG, LI ZHANG, LIYU XIE, SONGTAO XUE	DYNAMIC EXPERIMENT AND ANALYTICAL RESEARCH OF A CRANK INERTER SYSTEM
YU BAO, DIMITRIOS KONSTANTINIDIS	EFFECT OF AN ADJACENT WALL ON THE OVERTURNING OF A SLIDING-ROCKING BLOCK SUBJECTED TO PULSE EXCITATION
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SABINE LOOS, DAVID LALLEMANT, JAMIE MCCAUGHEY, NAMA BUDHATHOKI, FEROZ KHAN, RITIKA SINGH, JACK BAKER	BEYOND BUILDING DAMAGE: MODELING POST-DISASTER NEED
TAKAO NISHIZAWA, RYOTA SUEKUNI	OUTLINE OF STRUCTURAL DESIGN FOR KYOTO CITY HALL
GUIXIN ZHANG, BAITAO SUN	SEISMIC CAPABILITY OF BUILDING AND RISK ANALYSIS OF EARTHQUAKE DISASTER OF CHINESE MAINLAND
TIZIANO PEREA, JOSÉ ANTONIO SIFUENTES, GELACIO JUÁREZ-LUNA	STRUCTURAL ASSESSMENT OF STEEL BEAM-TO-COLUMN CONNECTIONS SUBJECTED TO CYCLIC LOADING BY NONLINEAR FINITE ELEMENT ANALYSIS
HAOWEN ZHENG, SHOICHI KISHIKI, NOBUHIKO TATSUMI, TAKANORI ISHIDA, YOSHINAO KONISHI	QUICK INSPECTION METHOD OF U-SHAPED STEEL DAMPERS BASED ON RESIDUAL DEFORMATION

KEN-ICHI FUJITA, HARUMI YASHIRO	EVALUATION OF HUMAN DAMAGE IN EVACUATION FROM TSUNAMI FOR A COMMON SCENARIO EARTHQUAKE
SATOSHI YAMAGAMI, HIDETAKA FUNAKI, YOSHIKI KOYAMA, HAJIME YAMAGIWA	DYNAMIC CHARACTERISTICS OF SEISMICALLY ISOLATED STRUCTURES IN MICROTREMOR
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RICHARD CHRISTENSON, MUAMMER AVCI	BASE ISOLATION STUDIES USING REAL-TIME HYBRID SIMULATION AND FIXED BASED BUILDING SHAKE TABLE TESTS
KAZUHIRO KANEDA	INVESTIGATION OF LATERAL VISCOUS BOUNDARY IN TWO PHASE DYNAMIC ANALYSIS OF 3D IRREGULAR LAYER SYSTEM GROUND
LUIS MARTIN LAVADO DURAND, JORGE LUIS GALLARDO TAPIA, CLAUDIA MITIE HONMA	EXPERIMENTAL AND NUMERICAL ANALYSIS OF BEHAVIOUR IN COMPRESSION AND SHEAR OF HANDMADE CLAY BRICK MASONRY
MEGAN BOSTON, SHERRY BANEZ, TARA FERNANDEZ-RITCHIE, NICOLE FRUEAN, NATASHA PAIRIS, MARK LAY	TOWARDS CREATING RESILIENT CITIES: A CASE STUDY OF HAMILTON, NEW ZEALAND
YOSHIMASA SHIGENO, KIYOSHI YAMASHITA, JUNJI HAMADA	SEISMIC PERFORMANCE OF A PILED RAFT FOUNDATION WITH GRID-FORM DMWS CONSIDERING SOFTENING OF STABILIZED SOIL
FUMINO SUZUKI, KENICHI KATO, TETSUSHI WATANABE, YUSUKE TOMOZAWA	STRONG GROUND MOTION SIMULATION OF THE GREAT 1923 KANTO EARTHQUAKE IN THE TOKYO METROPOLITAN AREA BASED ON STRONG MOTION GENERATION AREA
ATSUSHI AOI, HIROSHI TSUNEKAWA, MUTSUHIRO YOSHIZAWA, ATSUSHI KANBAYASHI, SHUN'ICHI TANO, GANBAT NYAMKHUU	STUDY ON DAMAGE ESTIMATION BY MACHINE LEARNING OF RELATIONSHIP BETWEEN BUILDING RESPONSE AND DAMAGE
TREVOR ALLEN, JONATHAN D GRIFFIN, DAN J CLARK, HADI GHASEMI	REFLECTIONS ON THE NSHA18: WHAT WAS DONE WELL? WHAT COULD BE DONE BETTER?
KENTARO NAKAI, TOSHIHIRO NODA, SHINYA FUKUDA, HIDEHIKO MURAO, AKIRA ASAOKA	LOCALIZED/ENORMOUS SEISMIC DAMAGE OF SUBSURFACE GROUND INDUCED BY THE STRATUM IRREGULARITY
TOSHIHIRO NODA, KENTARO NAKAI	SEISMIC DAMAGE OF SOFT CLAY LAYER DIRECTLY UNDER THE RIVER LEVEE THAT BECOMES PROMINENT BY L2 EARTHQUAKE
GANESH KUMAR JIMEE, K. MEGURO, A. M. DIXIT, ADITYA TAMANG	DISASTER RISK REDUCTION AND MANAGEMENT AT LOCAL GOVERNMENTS IN NEPAL: POLICIES, CHALLENGES & ROAD AHEAD
PAOLA PANNUZZO, TAK-MING CHAN	NUMERICAL ASSESSMENT OF THE FLEXURAL BEHAVIOR OF HOT-FINISHED STEEL BEAMS UNDER MONOTONIC AND CYCLIC LOADING
GEOFFREY W RODGERS, VISHNUPRIYA VISHNUPRIYA, JAMES GEOFFREY CHASE, CONG ZHOU	UPPER AND LOWER BOUNDS OF DEVICE FORCE CAPACITY IN HIGH FORCE TO VOLUME (HF2V) DEVICE DESIGN
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PRADEEP POKHREL, JIRO KUWANO	STABILITY OF UNDERGROUND CAVITY SUBJECTED TO SEISMIC MOTION
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ANNA MATSUKAWA, AYA TAUSJIOKA, FUMINORI KAWAMI, JUNKO MURANO, SHIGEO TATSUKI	INCLUSIVE DISASTER RISK REDUCTION WITH BEPPU MODEL: ASSESSMENT BY COMPARISON OF 37 MUNICIPALITIES IN HYOGO PREFECTURE

CHIN-LONG LEE	PROPORTIONAL VISCOUS DAMPING MODEL FOR MATCHING FREQUENCY-DEPENDENT DAMPING RATIO
MASARU OKUTSU, AKIRA ITO, KOUJI ITASAKA, MINORU TANAKA	DAMAGES OF TELECOMMUNICATION FACILITIES DUE TO THE 2016 KUMAMOTO EARTHQUAKE
JUNJI KIYONO, KENJI FUKUNAGA, RYOTARO MABUCH, MASATSUGU SHINOHARA, TAKAFUMI ITO	SEISMIC BEHAVIOUR OF VEHICLES ON HIGHWAY
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PAOLO CLEMENTE, FERNANDO SAITTA	SEISMIC ANALYSIS OF A TWO-SPAN MASONRY ARCH BRIDGE
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YOSHINOBU MIZUI, HIROYUKI FUJIWARA	DEVELOPMENT AND UTILIZATION OF NANKAI TROUGH EARTHQUAKE DISASTER INFORMATION PLATFORM
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DAMAGE ASSESSMENT OF RENTAL LOW-COST HOUSING FLATS IN CENTRAL SULAWESI INDONESIA AFFECTED BY PALU EARTHQUAKE

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Abstract

Several rental low-cost housing flats built under the program initiated by the Ministry of Public Works and Housing were among those affected by a strong earthquake on September 28, 2018, which was centered in the Palu Koro Fault in Central Sulawesi. One of the important characteristics of the Palu earthquake is the significant vertical earthquake acceleration. The structures of the affected housing flats were designed to be earthquake-resistant according design codes valid at the time of construction. The structural systems used on those buildings were varied including conventional reinforced concrete, precast concrete, or prestressed precast concrete. This paper presents the performance of the structure of rental housing flats in Palu area based on the results of a qualitative and quantitative survey conducted from October to December 2018 in 21 towers at 21 different locations. The study shows that the performance of the rental low-cost housing flat structures is good because design development and implementation fully complies with the requirements of design codes and construction specifications set by the Indonesian National Standard. However, in some areas where vertical earthquake is dominant, some buildings were severely damaged because the earthquake in the form of vertical wave as taken place in Palu is not covered in building design codes. Nevertheless, rental low-cost housing flats built by the Ministry of Public Works and Housing are seen to be performing quite well compared to other buildings around them. In addition, the use of precast technology in rental low-cost housing flat structures results in better performance compared to that of conventional system because of better quality control during construction.

Keywords: palu; vertical earthquake; retrofitting; precast; damage level

1. Introduction

A series of earthquakes shook Palu and Donggala areas on September 28, 2018 with its largest recorded magnitude of 7.4 Mw and with its important characteristic of significant vertical ground motion component. These events caused many loss of life and various degrees of damages to buildings and infrastructures in the impacted areas. Among those impacted buildings are several rental low-cost housing flats built under the program initiated by the Ministry of Public Works and Housing and started in 2002.

To determine the damage severity and help the local government planning for further action on the housing flats, structural assessment needs to be carried out. As such, the Ministry of Public Works and Housing sent structural engineering experts to Palu and Donggala areas to inspect and assess structural conditions of housing flats. This study will report and discuss structural and architectural conditions of 21 housing flats surveyed and inspected on 28 – 30 October 2018.

2. Palu Earthquake

Source of Palu earthquake is located 0.18 Southern Latitude and 11.85 East Longitude with the distance 26 km north of Donggala, Central Sulawesi and the depth of 10 km. Based on information gathered from local people experiencing the earthquake and analysis of shake map in Fig. 1, the ground motion was felt in Donggala (VII-VIII MMI), Palu, Mapaga (VI-VII MMI), Gorontalo dan Poso (III-IV MMI), Majene dan Soroako (III MMI), Kendari, Kolaka, Konawe Utara, Bone, Sengkang (II - III MMI), Makassar, Gowa, dan Toraja (II MMI). With reference to Table 1, Intensity scale of VI-VII MMI means that standard building structures may suffer moderate damage while non-standard building may suffer major damage. On the other hand, intensity scales of III-IV MMI means that the shaking felt by all people in the affected area but no damage is expected. However, if buildings hit several times by a series of earthquake, light damage might occur.

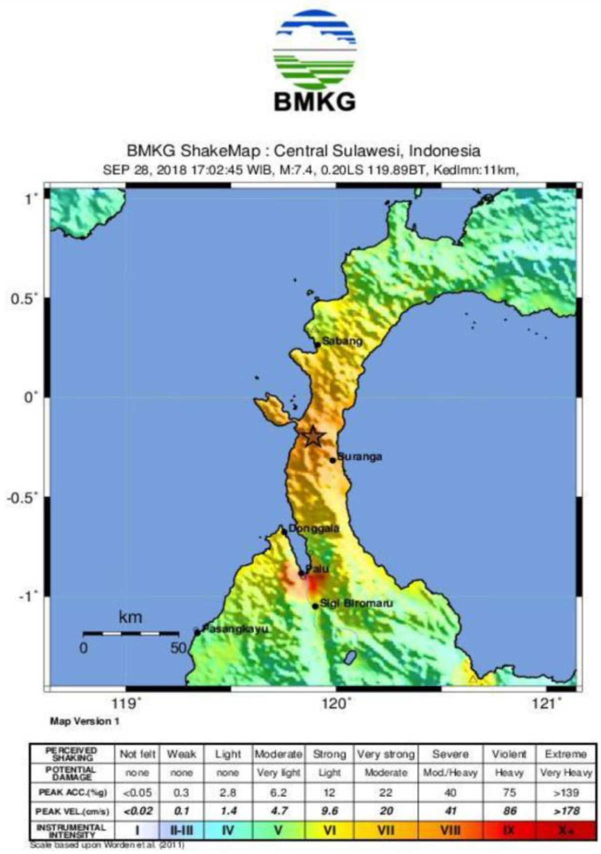

Fig. 1 – BMKG ShakeMap, Modified Mercalli Intensity Scale (MMI): Central Sulawesi, Indonesia

Table 1 – Modified Mercalli Intensity Scale (MMI) of 1931

I. Not felt	Not felt except by very few under especially favorable conditions.
II. Weak	Felt only by a few people at rest, especially on upper floors of buildings.
III. Weak	Felt quite noticeably by people indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV. Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V. Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI. Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII. Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII. Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX. Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Liquefaction.
X. Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI. Extreme	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII. Extreme	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

3. Material and Structural System of Housing Flats

Since most areas in Indonesia is at risk to earthquake, rental low-cost housing flats were designed to be structurally resistant against earthquake according to applicable Indonesian standards for building and seismic design at the time of construction. The main material used for construction is concrete. Conventional reinforced concrete, precast concrete, prestressed concrete or a combination thereof was employed in structural elements of housing flats. Any non-conventional technology used in the housing flats was first tested at Research Institute of Housing and Human Settlement, Indonesia.

4. Assessment Procedures

For this study, rapid assessment of structural and architectural condition of housing flats after Palu earthquake is conducted using visual and simple tools. Using guides [2-6] and previous studies [7-10], the conditions of buildings can be categorized into several damage levels and their corresponding required repair actions as follows:

- Minor damage of building
  a. No significant settlement of foundation
  b. No structural damage
  c. Architectural damage such as crack and spalling of skim coat cement and crack and spalling of plaster

  The required actions are to repair the damaged architectural components

- Moderate damage of building
  a. No significant settlement of foundation
  b. Cracked on structural component, but no significant change of shape
  c. Architectural damage in the form of crack on the wall and even hole on the wall on certain conditions, but no significant slope

  The required actions are to repair architectural and structural components

- Major damage of building
  a. Significant settlement of foundation

b. Spalling of structural components and even failed structural components, but no failure of overall structure
c. Architectural damage in the form of crack through the wall thickness, slope wall and even failure

There are several alternative actions that can be done on building experiencing major damage as follows:

a. If structural component damages do not cause significant change of shape on reinforcing bar and the overall building, then further investigation needs to be conducted to assess building structure
b. If there is significant settlement of foundation, then further investigation needs to be conducted to assess building structure
c. If structural component damages cause significant change of shape on reinforcing bar and the overall building, then the building can be stated as not functioning structurally.

- Failure of building
  a. Failure of foundation
  b. Fail on one or more structural components causing building failure

Several failure modes of structures that are critical and thus may cause buildings cannot function anymore are:

- Soft story effect
- Weak column strong beam
- Failure at beam-column joint
- Compressive failure

In this study, the following assessment procedure was used:

1. Conduct visual investigation to record structural and non-structural (architectural) damages
2. Compare between recorded damage data and damage criteria
3. Determine the level of damage criteria
4. Propose actions that need to be done based on the damage level

Data employed in this study:

1. Secondary earthquake data from Meteorological, Climatological, and Geophysical Agency, Indonesia.
2. Pictures taken during survey of visual examination.

Condition assessment surveys of housing flat buildings in di Central Sulawesi post-earthquake were conducted at 21 different locations during the period of 28 – 30 October 2018. From these surveys, it was found that structural and non-structural (architectural) damage conditions vary from minor to major damages.

5. Results and Discussions

From survey and analysis of conducted on housing flat structures affected by Palu earthquake, it shows that, from 21 existing housing flats being investigated, there are 18 housing flats having light structural damage, 2 having moderate damage and 1 having major structural damage. Meanwhile, from architectural investigation, there are 17 housing flats having light architectural damage, 3 housing flats having moderate architectural damage and 1 housing flat having major architectural damage.

Housing flats that suffer moderate and major structural damage are:

- Moderate damage (2 housing flats): MTs DDI Lonja and UPT Dinas PU Palu (Fig. 2)
- Major damage (1 housing flat): Univ. Tadulako – Palu (Fig. 3).

Meanwhile, housing flats that suffer moderate and major architectural damage are:

- Moderate damage (3 housing flats): Univ. Al-Khairat Palu, Rusunawa Pekerja Kota Palu dan UPT Dinas PU Palu
- Major damage (1 building): Univ. Tadulako – Palu

Fig. 2 – Front view of damage occurred on rental low-cost housing flat UPT Dinas PU Palu

Fig. 3 – Front view of damage occurred on rental low-cost housing flat Univ. Tadulako

Figure 4 shows the distribution of 21 housing flats suffering various degrees of structural damage. These are housing flats built in the period of 2007-2017. As can be seen, most housing flats have only minor damage. This shows that the seismic performance of those housing flats are good as many buildings around them are severely damaged. In other words, the housing flats perform well against designed earthquake load. One housing flat that suffer major damage is housing flat Univ. Tadulako – Palu constructed using conventional reinforced concrete.

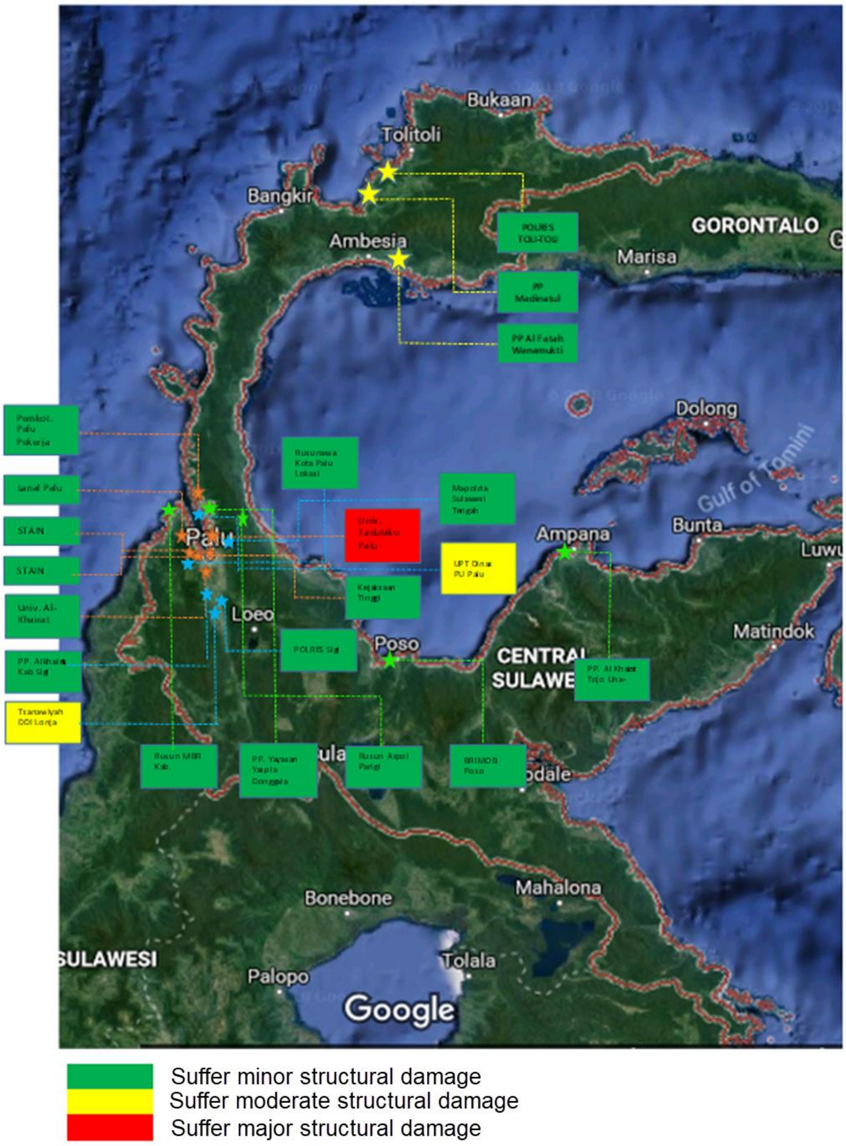

Fig. 4 – Mapping of housing flats suffering structural damage due to earthquake

Distribution of 21 housing flats suffering various degrees of architectural damage is shown in Fig. 5. As can be seen, most housing flats have only minor architectural damage.

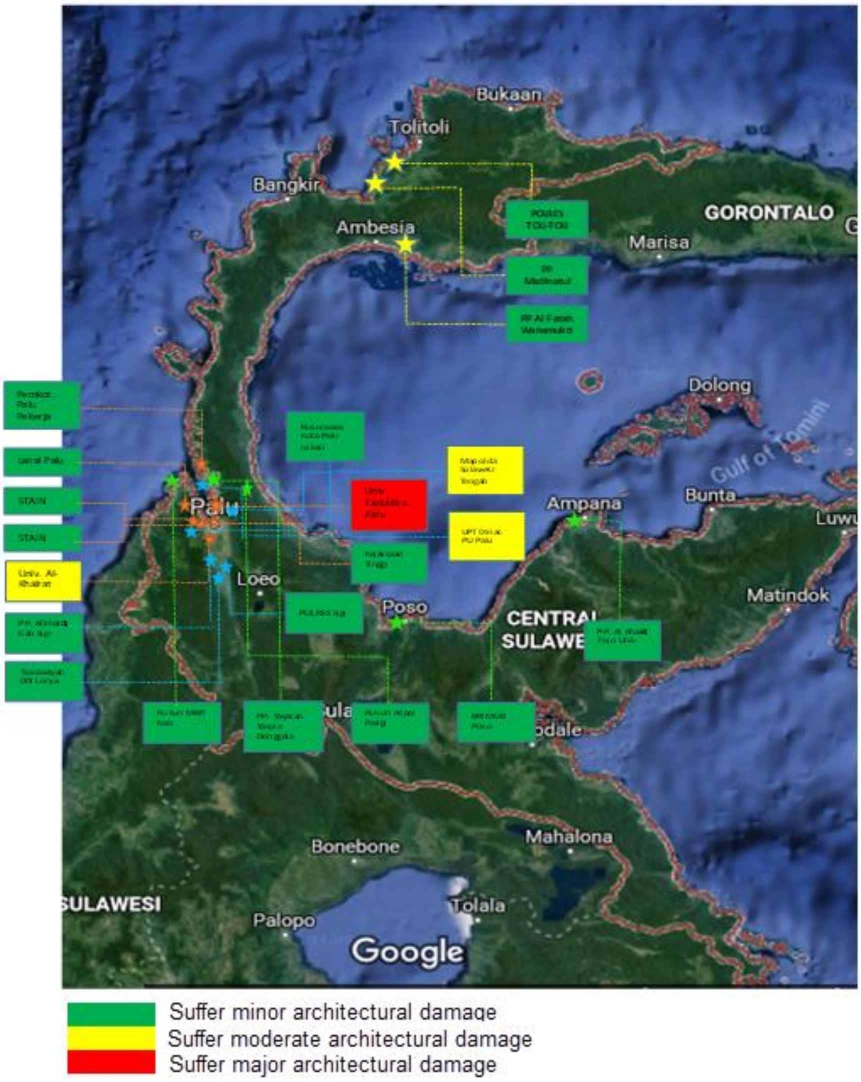

Fig. 5 – Mapping of housing flats suffering architectural damage due to earthquake

Table 2 shows summary of damage occurred on the investigated housing flats. As can be seen, the majority of housing flats perform well under earthquake load.

Table 2 – Summary of damage levels on 21 housing flats investigated in this study.

Damage Level	**Structural Damage**	**Architectural Damage**
Minor	18	17
Moderate	2	3
Major	1	1

6. Conclusion

Overall, rental low-cost housing flats in Central Sulawesi built by Ministry of Public Work and Housing of Indonesia perform well against earthquake load especially the ones using precast concrete system. It is because the precast concrete system is prefabricated in controlled environment, thus better quality. In addition, the study also shows the importance of complying with building design codes published by Indonesia National as buildings designed according to Indonesia building codes perform well against the expected seismic design loads.

7. Acknowledgements

The Financial support provided by Ministry of Public Works and Housing for this research is highly appreciated.

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