相關研究
報告摘錄

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Title no. 110-M43

Design of Concrete Mixtures with Recycled Concrete Aggregates

by Adam M. Knaack and Yahya C. Kurama

This paper investigates the workability, compressive strength, and elastic modulus of normal-strength concrete with recycled concrete aggregate (RCA) as replacement for coarse natural aggregate (for example, crushed stone, gravel). To represent the variability in material quality and properties, 16 different RCA sources are used in the experimental program. Three RCA concrete mixture design methods using varying amounts of direct volume aggregate replacement, direct weight replacement, and equivalent mortar replacement are compared. It is found that these different mixture design methods result in similar compressive strength and elastic modulus of RCA concrete; however, the workability of RCA concrete may be considerably reduced when using the equivalent mortar replacement method. While the effect of increased amounts of RCA on the concrete compressive strength is generally small for all three mixture design methods, the concrete elastic modulus is more significantly affected by RCA. A multiple least-squares regression analysis of the test results is conducted to develop predictive design relationships for the strength and stiffness of RCA concrete. The results suggest that the RCA water absorption and deleterious material content can be used to prequalify the material for selected concrete strength and stiffness performance objectives.

Keywords: compressive strength; mixture design; modulus of elasticity; mortar; recycled concrete aggregate; slump; workability.

INTRODUCTION

This paper focuses on the use of recycled concrete aggregate (RCA) as replacement for coarse natural aggregate (for example, crushed stone, gravel) in normal-strength structural concrete applications. About two-thirds of the construction and demolition waste in the United States consists of old concrete rubble, which is routinely made into recycled concrete aggregates.[1] The coarse fraction from this material readily passes the requirements for coarse aggregates in structural concrete[2]; however, the use of recycled concrete as aggregate in new construction has been largely limited to nonstructural applications such as sub-base for roadways.[3] The preparation of RCA (that is, demolition, crushing, sieving/grading, and washing) for structural applications does not require a drastically different process than what is currently used for nonstructural applications. In comparison, the use of natural coarse aggregates has added costs due to potentially increased transportation distances and adverse effects on the ecology of forested areas and riverbeds, while also requiring the processes of mining, crushing (except for some gravel), sieving/grading, and washing. By recycling old concrete as replacement for coarse natural aggregates in new construction, it may be possible to reduce the demand for new aggregates and improve the sustainability of concrete structures.

Most of the previous research on RCA concrete was conducted outside the United States (refer to "Background"), limiting the adoption of the findings domestically because of variations in materials and quality control. To advance the use of RCA in structural applications, it is necessary to develop a mixture design methodology that consistently provides desirable fresh and hardened concrete properties using a straightforward mixture proportioning approach. It is also essential to determine the effects of RCA on the mechanical properties of concrete. With these objectives, this paper provides an experimental evaluation of three RCA concrete mixture design methods: 1) direct weight replacement; 2) equivalent mortar replacement; and 3) direct volume replacement. A large number of concrete mixtures using varying amounts of RCA are compared based on workability, compressive strength, and elastic modulus. Sixteen different RCA sources from the Midwestern United States are included in the study to investigate the variability of RCA properties. The resulting experimental database is then used in a statistical analysis to develop predictive design relationships for the prequalification of RCA with selected concrete strength and stiffness performance objectives. Full information about the research program and the test results can be found in the project website at: www.nd.edu/~concrete/RCA-concrete/.

RESEARCH SIGNIFICANCE

RCA supplies exceed the current demands in many parts of the country.[4,5] In the years to come, the renovation of our aging infrastructure will result in both a further increase in the supply of RCA as well as an increase in the demand for new concrete. In many cases, the demolished structure may be near the new construction, thus allowing better quality control and reduced transportation costs. While the need for a more sustainable use of our natural resources provides impetus for the increased use of RCA, there are currently no engineering standards for the design of concrete structures containing RCA. This paper provides basic information for the use of this material in structural applications.

BACKGROUND

This section describes three RCA concrete mixture design methods that are explored in this paper. Previous work on the relevant properties of RCA concrete is also discussed. Note that due to paper length requirements, a limited number of references were included.

Direct weight replacement (DWR) method

The direct weight replacement (DWR) method has been used extensively throughout the literature,[6-10] most likely due to its simplicity. In this method, the weight of the total coarse aggregate in the concrete mixture (that is, coarse

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natural aggregate plus RCA) is kept constant for any aggregate replacement ratio. The water content (mixing water beyond saturated surface-dry condition of the aggregates) and cement content are also kept constant; however, to produce the same volumetric yield (Fig. 1), a small reduction in the amount of fine aggregate may be made because, depending on the specific gravity, an equal weight of RCA typically occupies a greater volume than coarse natural aggregate (NA). It has been reported[6] that a gradual reduction in concrete workability occurs with DWR, possibly due to the increased volume of coarse aggregate in the mixture.

Equivalent mortar replacement (EMR) method

The equivalent mortar replacement (EMR) method, proposed by Fathifazl et al.,[7] treats RCA as a two-phase material made of coarse recycled natural aggregate (RNA) (that is, coarse natural aggregate in the RCA) and residual mortar (that is, mortar attached to the RNA) rather than as a single coarse material. The volume of the residual mortar (RM) is accounted for so that the EMR mixture has the same volume of total mortar (that is, residual plus fresh mortar) and the same volume of total coarse natural aggregate (that is, recycled plus new coarse natural aggregate) as the target natural aggregate concrete (NAC) mixture, which can be stated as

$$V_{RM}^{EMR} + V_{FM}^{EMR} = V_{FM}^{NAC} \text{ and } V_{RNA}^{EMR} + V_{NA}^{EMR} = V_{NA}^{NAC} \qquad (1)$$

where V_{RM}^{EMR} is the volume of residual mortar (RM) in the EMR mixture; V_{FM}^{EMR} is the volume of fresh mortar (FM) in the EMR mixture; V_{FM}^{NAC} is the volume of FM in the NAC mixture; V_{RNA}^{EMR} is the volume of coarse recycled r aggregate (RNA) in the EMR mixture; V_{NA}^{EMR} is the v of new coarse natural aggregate (NA) in the EMR mi and V_{NA}^{NAC} is the volume of coarse natural aggregate NAC mixture.

Equation (1) dictates that as V_{RM}^{EMR} is increased due to increased RCA in the mixture or increased RM RCA), the amount of fresh mortar, V_{FM}^{EMR} (cement + w fine aggregate; refer to Fig. 1) is decreased while ke the relative proportions of cement, water, and fine agg constant. Also according to Eq. (1), increased V_{RM}^{EMR} (t decreased V_{RNA}^{EMR}) requires the addition of more new natural aggregate V_{NA}^{EMR} to achieve equivalent volun total coarse natural aggregate in the mixture. Beca reduction in the amount of fresh mortar reduces the ability of the concrete, there is a limit to the max aggregate replacement in EMR mixtures. As a resu EMR mixtures in Fathifazl et al.[7] used significant an of water-reducing admixtures and relatively low lev aggregate replacement. While both EMR and DWR m were evaulated by Fathifazl et al.,[7] the mixtures did no similar aggregate replacement percentages, thus m direct comparisons difficult.

Direct volume replacement (DVR) method

ACI 211.1[11] provides a method for proportionin concrete mixtures based on the volume of each const This so-called direct volume replacement (DVR) m has also been used previously in designing RCA co mixtures[12-15] and is investigated herein as a simple m consistent with standard practice for conventional m designs. The DVR method treats RCA as a single- coarse aggregate where a given volume of NA in the mixture is replaced by the same volume of RCA (F Because the resulting volumetric proportions of total aggregate (RCA plus NA), fine aggregate, cemen water remain constant, there should not be a significa in workability of DVR concrete other than any effects differences in the surface texture and angularity of the gates, as long as the greater absorption of RCA (as com with NA) is incorporated into the design.

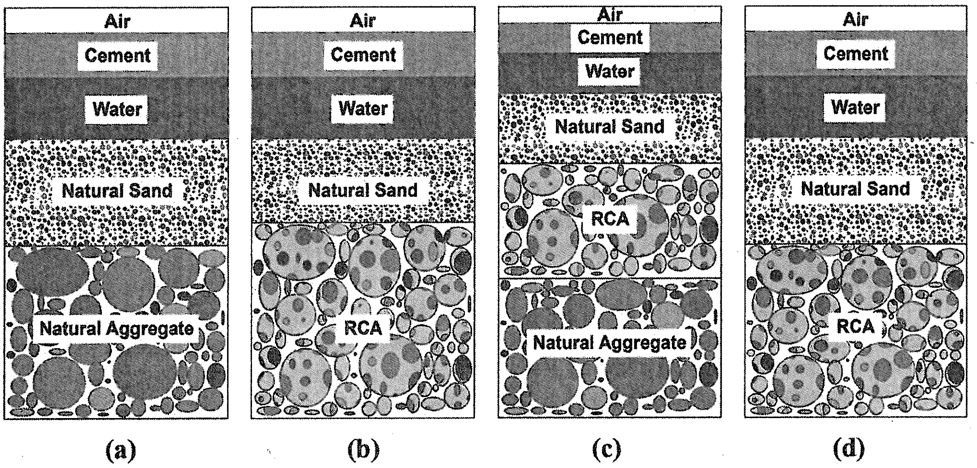
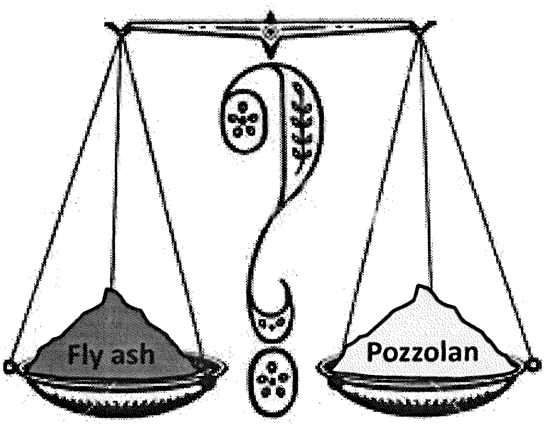


Fig. 1—Concrete mixture design methods: (a) NA concrete mixture; (b) DWR mixture with R = *100%; (c) EMR mixture with* R *=20% (maximum allowed for mixtures with NA-PG target by workability limit); and (d) DVR mixture with* R *=100%.*

The Potential of Natural Pozzolans to be a Class F Fly Ash Replacement in Concrete



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University of Texas at Austin

Project sponsored by Texas Department of Transportation (TX 0-6717)

MOTIVATION

- Uncertain supply of fly ash in the future due to EPA regulations that propose to classify it as a special waste.
- Air pollution reduction incentives are making power plants switch to coal sources that do not produce good quality Class F fly ash.
- Estimated average annual cost of banning fly ash in the US is $5.23 billion (ARTBA, 2011).
- Imperative to find alternative SCMs (supplementary cementitious materials) that can provide similar strength and durability benefits to concrete as Class F fly ash.


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OUR RESEARCH

- Looks at the performance of natural pozzolans found in US:
    - ASTM C 618 requirements for Class N pozzolan
    - Compression Strength
    - Durability *(Alkali Silica Reaction & Sulfate Attack)*
    - Fresh State Properties

- 8 different pozzolans used in our research:
    - *Unaltered Volcanic Pozzolans*: Pumice, Perlite, Vitric Ash
    - *Altered Volcanic Pozzolans:* Three Zeolites (1 fine, 2 coarse)
    - *Sedimentary Pozzolans:* Metakaolin, Shale

POZZOLAN PROPERTIES

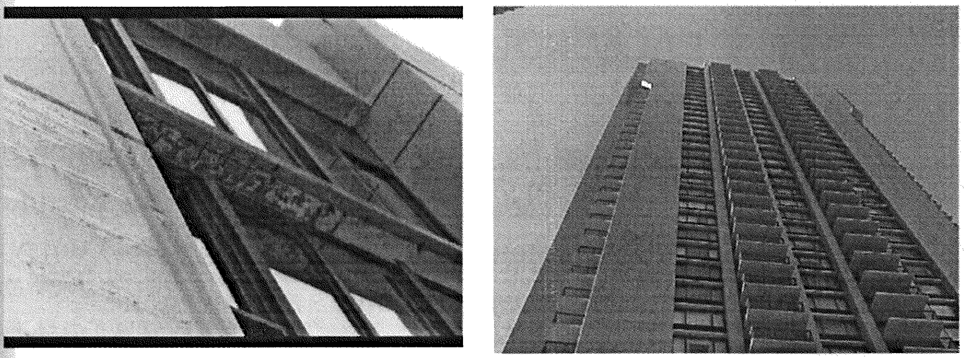
- All the pozzolans were rich in silica and alumina, having a $SiO_2+Al_2O_3+Fe_2O_3$ quantity of over 74%.
- Other than the three zeolites, all the pozzolans passed the ASTM C 618 requirements for a Class N pozzolan.
- The three zeolites that did not pass the ASTM C 618 mostly failed due to problems with water demand and moisture content.
- Two of the coarser zeolites also had problems with fineness requirement and showed a lower Strength Activity Index (SAI).

RESEARCH IN PROGRESS

- **Understanding why one SCM is working better than others**
- **Linking performance to the physical properties of the SCMs**
  - *Surface area analysis with BET*
  - *Finding crystalline content using XRD*
- **Determining the pozzolanic potential of the SCM**
  - *Finding the $Ca(OH)_2$ content of pastes using TGA*
- **Can properties can be modified to enhance performance?**
  - *Modifying zeolites to improve workability*
  - *Understanding why modifications improve/deteriorate performance*

CONCLUSIONS

- Other than the two coarse zeolites, Zeolite-T and Zeolite-A, all the pozzolans tested can be a suitable replacement for Class F fly ash.
- In terms of ***compressive strength***, the best performers were Pumice-D, Metakaolin-D, Shale-T and Zeolite-Z, having strengths higher than or similar to the control concrete at 90 days.
- In terms of resistance to ***ASR***, all the pozzolan concrete mixtures are well below the 0.04% expansion limit at 18 months.
- For resistance to ***sulfate attack***, the best performers were Pumice-D, Perlite-I, Metakaolin-D and Zeolite-Z, having expansions less than 0.10% at 1 year (Class 2 exposure).
- Zeolite-Z is a good performer, but it has some ***workability issues***.



ACI 546R REPAIR GUIDE
CHAPTER 4 MATERIALS

MARCH 23, 2014

TIMOTHY GILLESPIE - SIKA CORPORATION

CHRIS WHITE – JE TOMES & ASSOCIATES

BUILDING TRUST

AGENDA

- Background
- Concrete repair
- Crack repair
- Bonding materials
- Coatings on reinforcement
- Reinforcement
- Material selection
- Summary

BACKGROUND

- ACI 546R-04
  - 3.1 Introduction
  - 3.2 Cementitious materials
  - 3.3 Polymer materials
  - 3.4 Bonding materials
  - 3.5 Coatings on reinforcement
  - 3.6 Reinforcement
  - 3.7 Material selection
- 10 pages of text

- ACI 546R-XX
  - 4.1 Introduction
  - 4.2 Concrete replacement and overlays
  - 4.3 Crack repair materials
  - 4.4 Bonding materials
  - 4.5 Coatings on reinforcement
  - 4.6 Reinforcement
  - 4.7 Material selection
- 50 pages of text

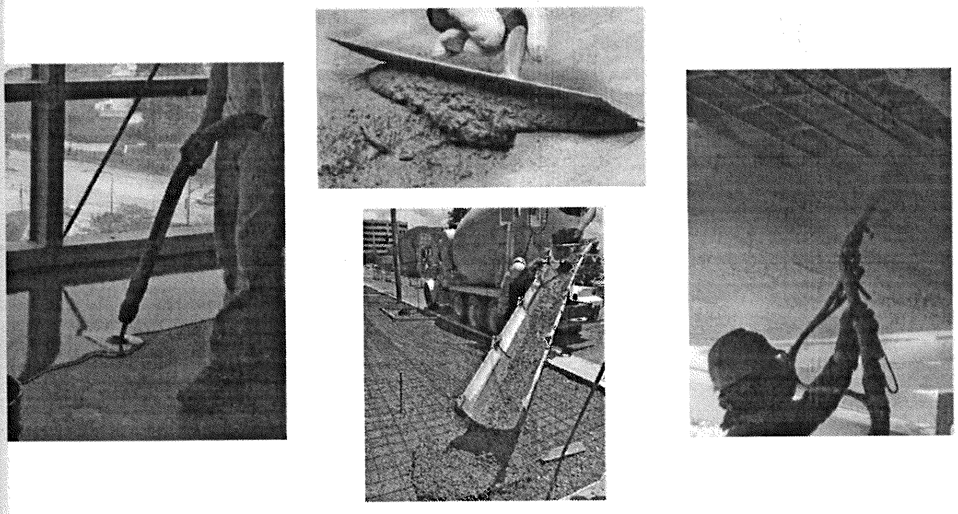
BACKGROUND

- Work began in F2005 / S2006
- Reorganize the chapter and harmonize with the Material Selection Guide
  - (ACI 546.3R-06)
- We refer readers to the Material Selection Guide for additional information on the materials
- Moved several application methods to Chapter 5 Concrete and reinforcing repair techniques
  - Shotcrete, dry-pack, pre-placed aggregate
- Added an entire new section Crack repair materials (similar to Material Selection Guide)

BACKGROUND

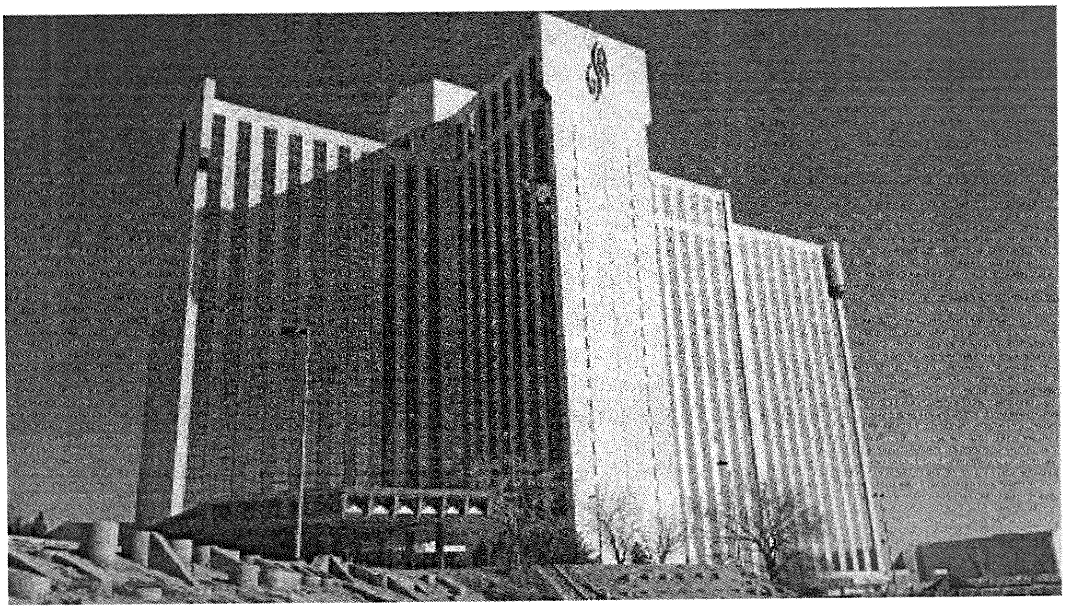
- Concrete replacement and overlays section
  - Previous version had 14 cementitious and 2 polymer type materials
  - Current version
    - 7 types (binder and packaging)
    - New section Supplemental cementitious materials (3)
    - New section Admixtures (6)
    - Other additives (1)
- Crack repair materials section
  - Not in previous version
  - 9 material types are covered
- 21 contributors
  - On the committee and/or selected experts
    - Reviewed current text and updated
    - Coordinated with the Material selection Guide
    - Wrote text for a new section

Concrete Replacements and Overlays



Cementitious Materials for the Repair of Concrete

活動剪影



本次 ACI 年會舉辦場館—The Grand Sierra Resort & Casino, Reno, NEVADA

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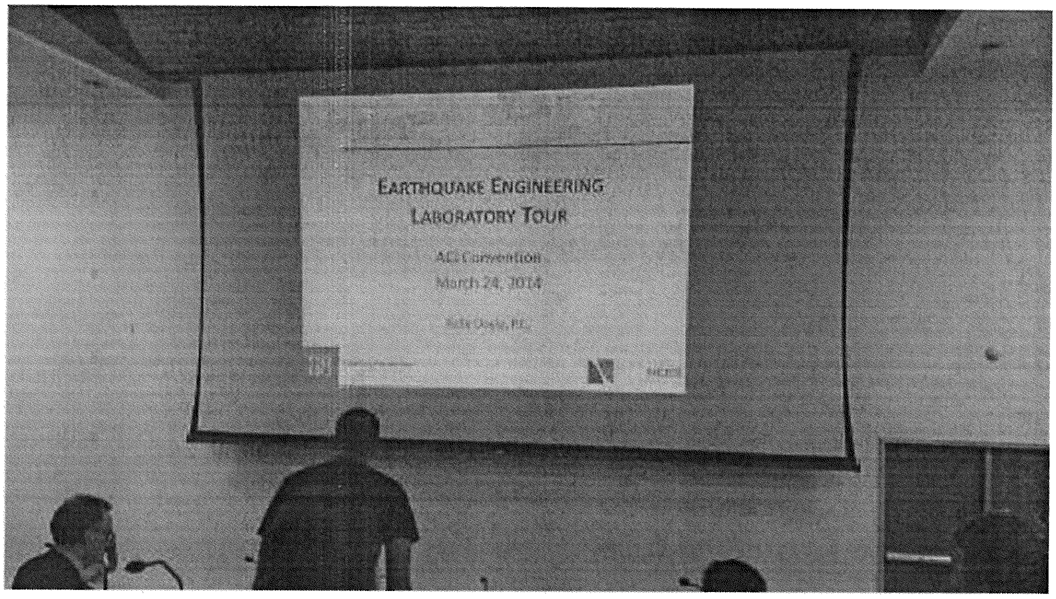

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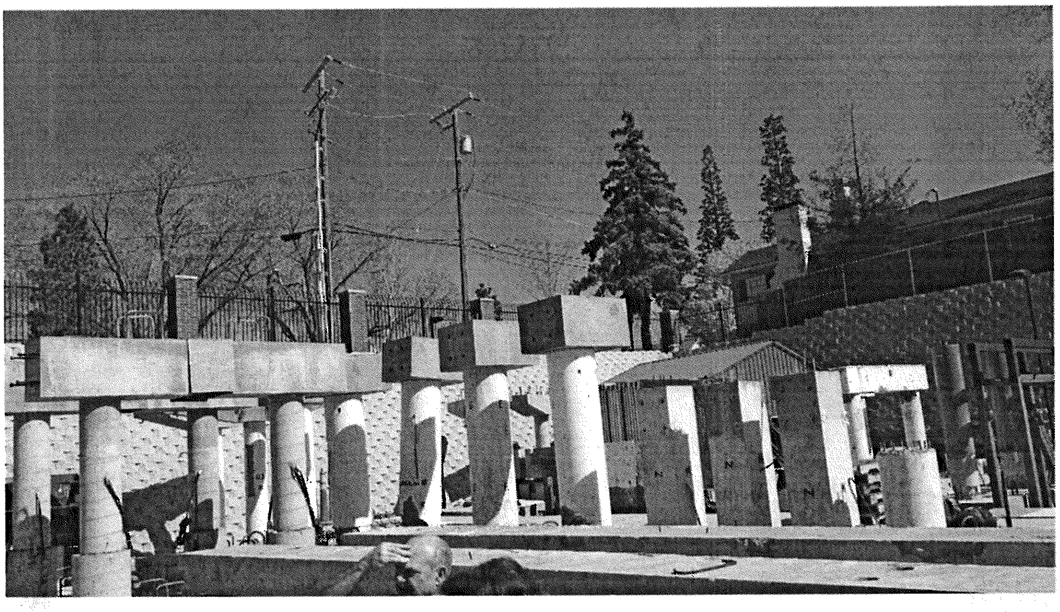

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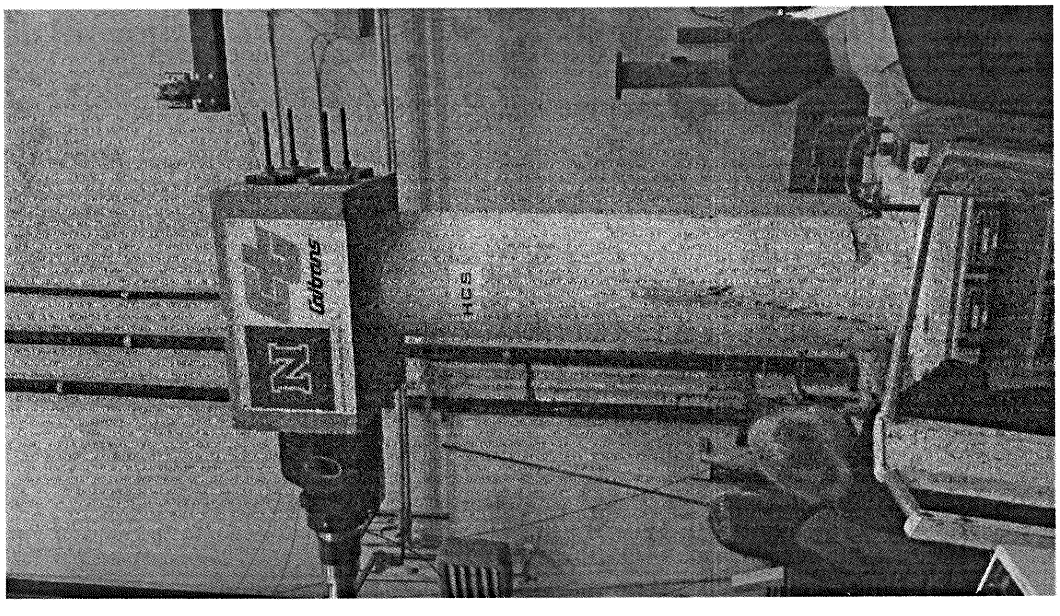

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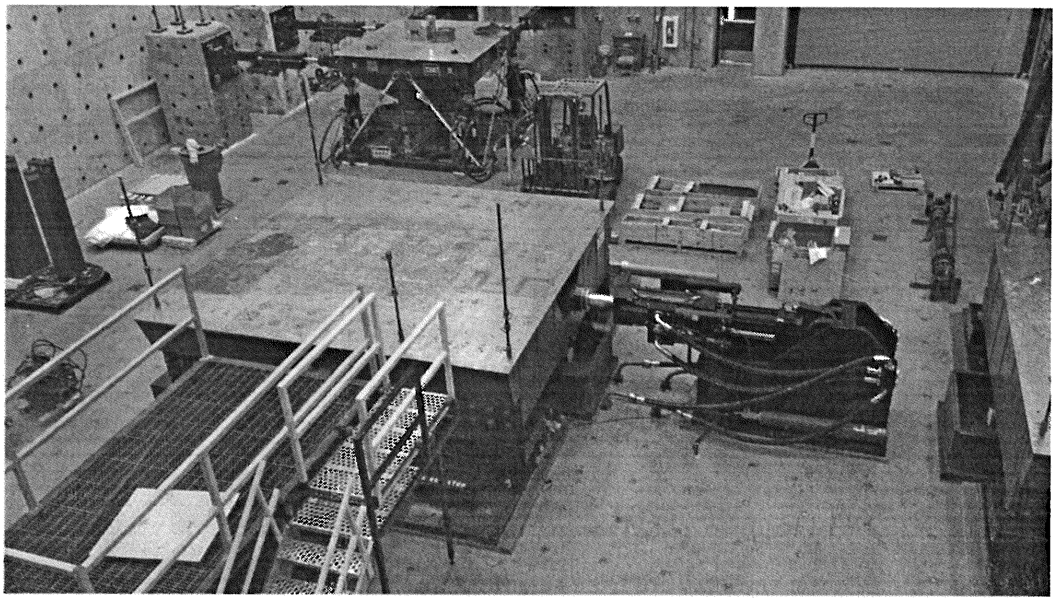

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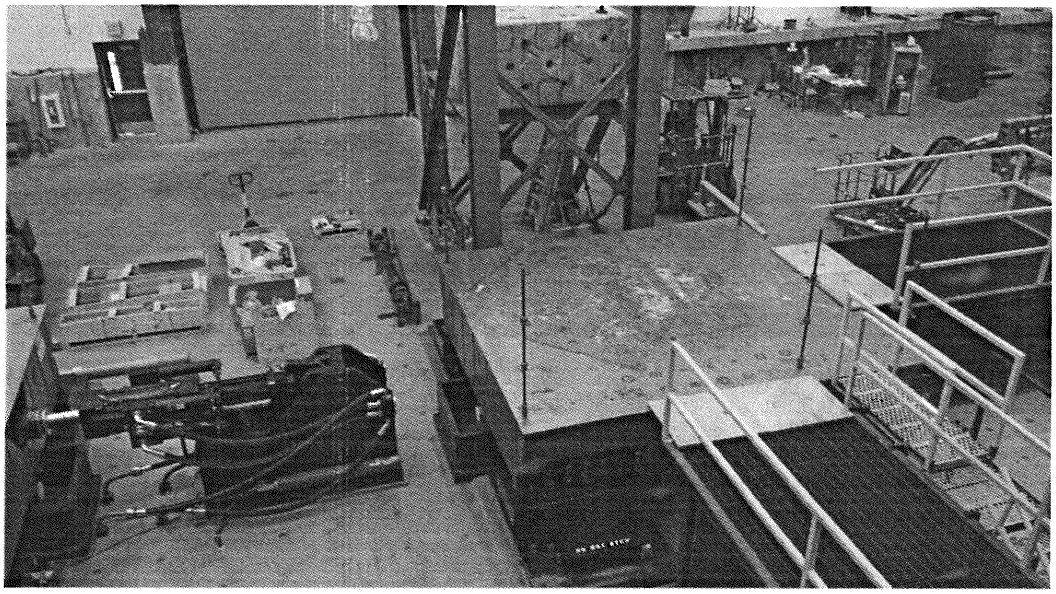
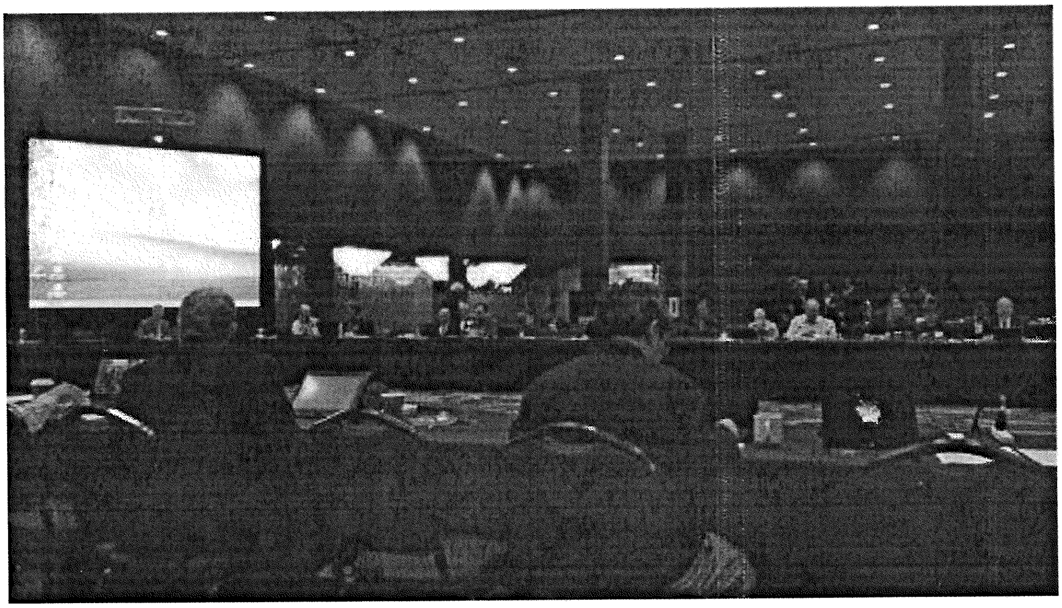


參觀地震工程實驗室-振動台試驗設備

分組技術委員會



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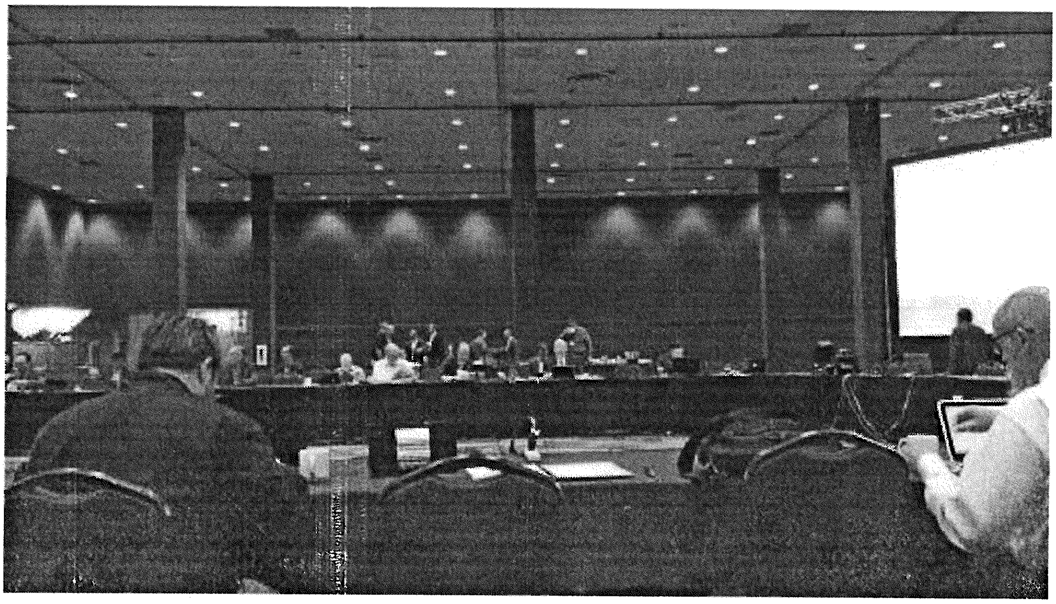

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技術委員會(三)