ملتقى الشارقة الأول للهندسة
Sharjah First Engineering Forum

جامعة أبوظبي
ABU DHABI UNIVERSITY

# الأسباب الجيوتكنيكية لتصدعات المباني والعمل على تفاديها

# *Geotechnical reasons for building cracks and how to work on avoiding them*


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*Department of Civil Engineering*
*Abu Dhabi University*
*Abu Dhabi, UAE*

***الدكتورة المهندسه ريم صابوني***
أستاذ مشارك
قسم الهندسة المدنية
جامعة أبو ظبي
أبو ظبي, الامارات العربية المتحدة

# مخطط العرض:

- تصنيف التصدعات في المباني
- التصدعات في المباني بسبب الهبوط
- تأثير التكهفات على التصميم الجيوتكنيكي للمبناني
- تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على تصميم الهياكل للمنشات
- تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على الاستجابة الحرارية للمنشات في الطقس الحار
- الاستنتاجات و التوصيات

# Presentation Outline:

- Classifications of Cracks in Buildings
- Cracks in Buildings Due to Settlement
- Effect of Cavities on the Geotechnical Design of Structures
- Effect of Soil Structure Interaction on Design of Structures
- The Influence of Soil Structure Interaction on Thermal Response of Structures in Hot Weather
- *Conclusions and Recommendations*

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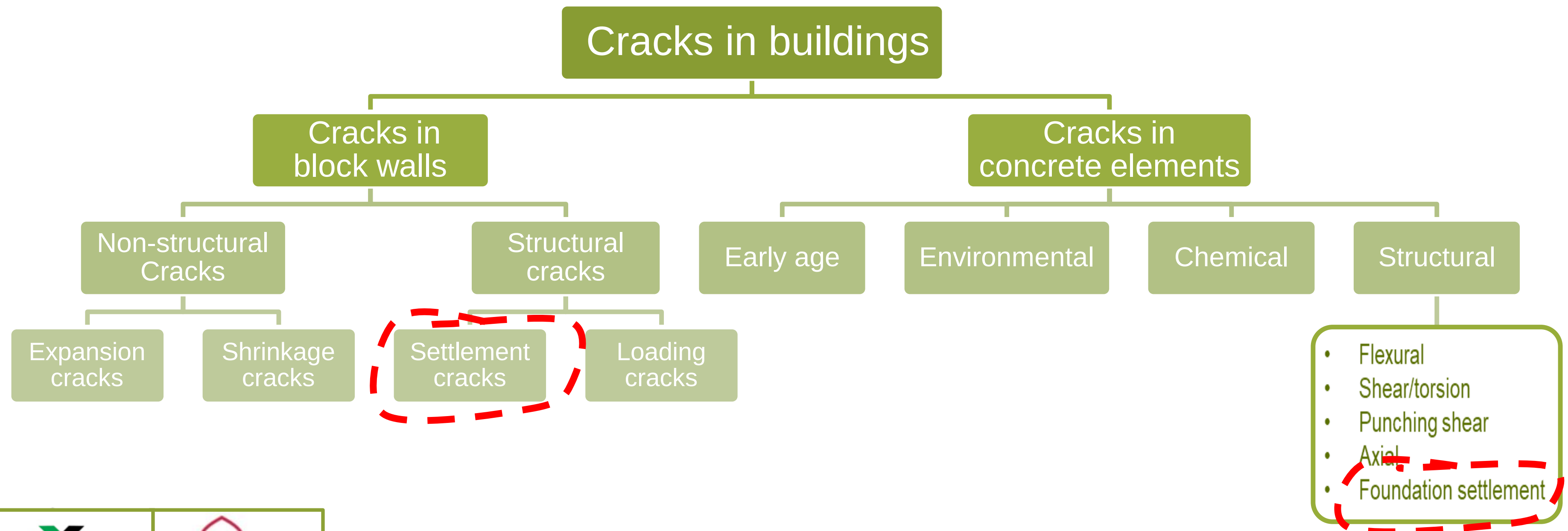
# Classifications of Cracks in Buildings

# تصنيف التصدعات في المباني

**A commonly known classification of cracks, based on their width is:**

- Thin - less than 1mm in width
- Medium - 1 to 2 mm in width
- Wide - more than 2 mm in width

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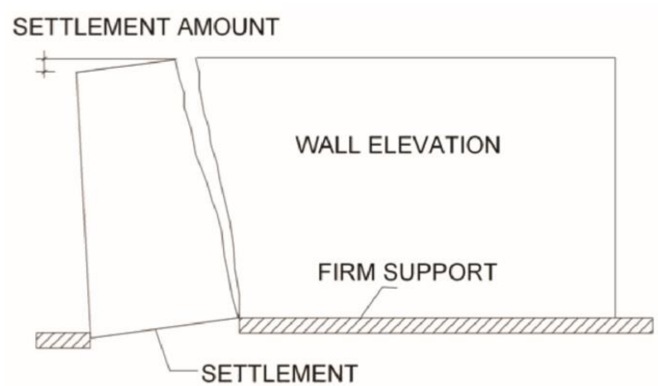
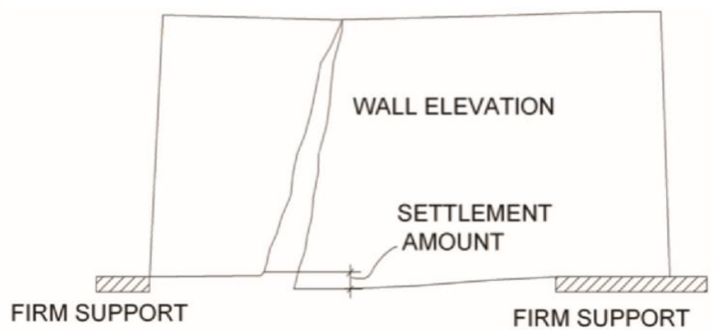
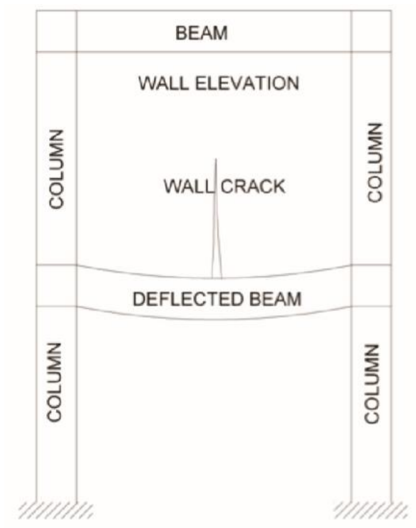
# Cracks in Buildings Due to Settlement
# التصدعات في المباني بسبب الهبوط

## Settlement Cracks:

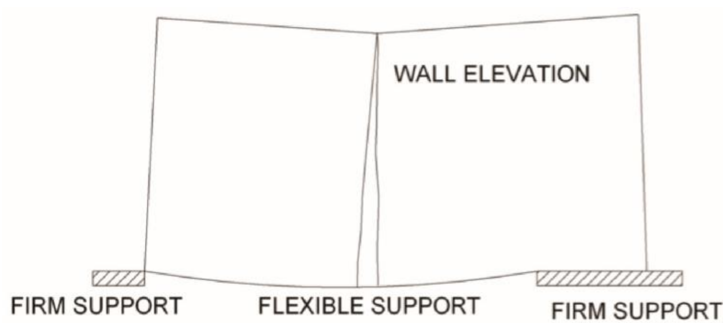


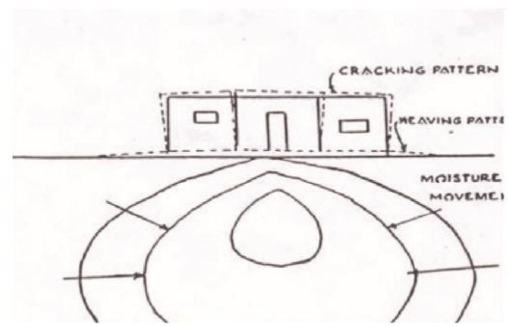

*differential settlements of supports(Cracks in Concrete)*




*Cracks in walls due to deflection of concrete beam.*




*Flexural cracks due to settlement at mid span of the wall(Cracks in Concrete)*




*Thermo-osmotic heaving of buildings on desiccated clay soils(Bureau of Indian Standards)*

# Cracks in Buildings Due to Settlement
# التصدعات في المباني بسبب الهبوط

## Diagnoses of cracks due to foundation settlement:

Differential settlement:

- Difficulty in operating doors or windows
- Cracking of plaster or gypsum wall board inclined at approximately 45$^{o}$
- Cracking in the masonry façade at approximately 45o on the diagonal in a stepwise fashion along the brick-mortar joints.
- Series of diagonal cracks between windows that are stacked vertically
- Inclined cracks at the corner of windows and doors

Uniform settlement:

- Damage of services connected to the structure

## Effects of foundation settlement:

Differential settlement:

- Serviceability and functional damage
- Impose significant stresses and alteration of the conditions on which the basic structural assumptions were made (e.g. regions of hogging moment may be subjected to sagging moment instead). These regions will be significantly under-strength
- Damage may affect the stability of the building such as cracking and distortions to support members which may lead to complete collapse of the building.

Uniform settlement:

- It will not normally cause structural distress but it may damage services connected to the structure

# Cracks in Buildings Due to Settlement
# التصدعات في المباني بسبب الهبوط

## Causes of settlement in foundation:

- Error in design of foundation
- Incorrect assumption about properties and distribution of the soil below the structure
- Error in structural design of elements such as pile caps
- Consolidation of a soft and/or organic soil
- Presence of expansive soil.
- Settlement from uncontrolled deep fill
- Development of limestone cavities or sink holes
- Soil subsidence Extraction of oil or ground water
- Water infiltration into the ground that may cause unstable soil to collapse
- Yielding of adjacent excavations or collapse of limestone cavities and underground mines and tunnels

# Cracks in Buildings Due to Settlement
# التصدعات في المباني بسبب الهبوط

## PRECAUTIONS TO AVOID FOUNDATION SETTLEMENT

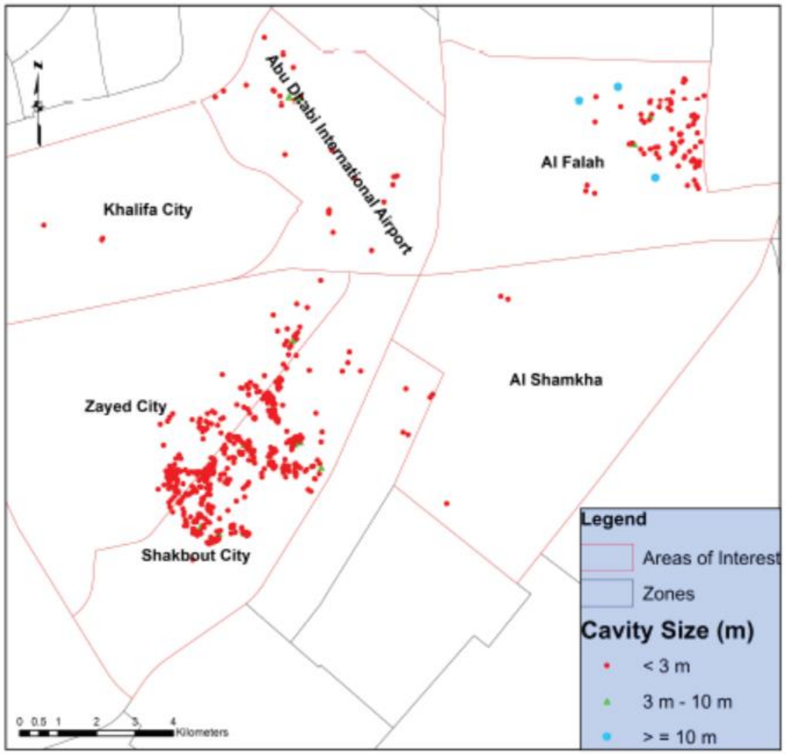
- Proper soil investigation and subsurface exploration
- Proper design of foundation and tie beams
- Proper compaction of soil layers as per the soil investigation report
- Avoid excessive irrigation near foundation to minimize water infiltration into the ground
- Avoid soil subsidence extraction of oil or ground water beside foundation
- A void deep excavation beside foundation of existing building unless proper earth retaining walls are provided by means of Contiguous Bored Piled Wall, Secant Piled Wall, or Diaphragm (D-wall).
- Proper isolation of foundation to avoid deterioration due to presence of water table or aggressive agents.
- Proper drainage system to avoid leaking and/or water infiltration into the ground.

# Effect of Cavities on the Geotechnical Design of Structures

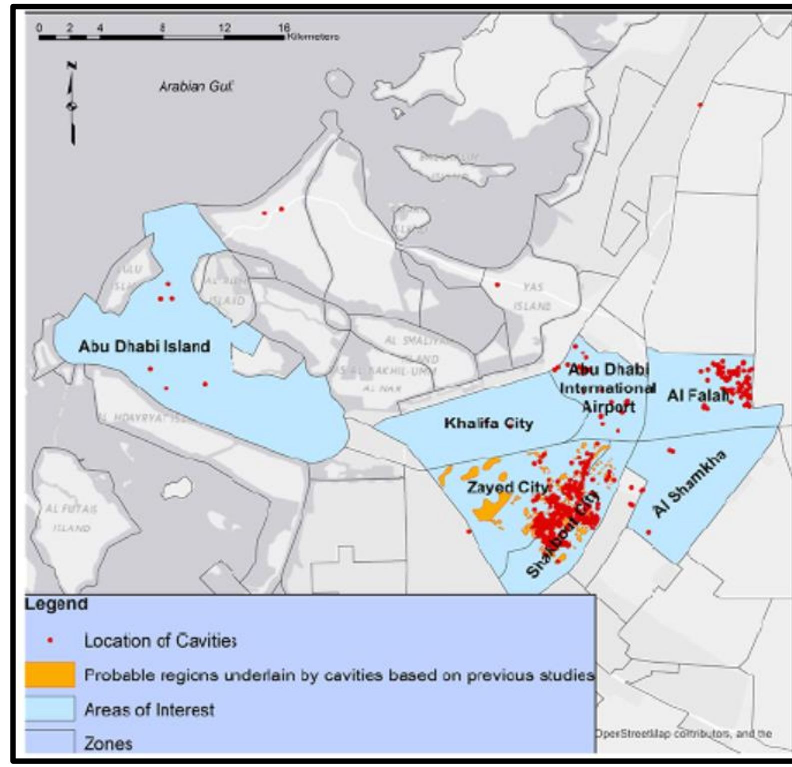
# تأثير التكهفات على التصميم الجيوتكنيكي للمباني

## Cavity distribution maps in Abu Dhabi:

## خرائط توزيع التكهفات الجوفية في أبو ظبي:




Spatial distribution of cavities in the Abu Dhabi Municipality.




Cavity distribution in Abu Dhabi Municipality is concentrated in regions such as Zayed City, Shakbout City, regions around the Abu Dhabi Airport and Al Falah.

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# Effect of Cavities on the Geotechnical Design of Structures

# تأثير التكهفات على التصميم الجيوتكنيكي للمباني

- **Examples of Structures Above Cavities in Abu Dhabi, UAE**
- **أمثلة على منشات واقعة فوق تكهفات في مدينة أبو ظبي ، الإمارات العربية المتحدة**




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# Effect of Cavities on the Geotechnical Design of Structures

# تأثير التكهفات على التصميم الجيوتكنيكي للمباني

## Examples of Structures Above Cavities in Abu Dhabi, UAE

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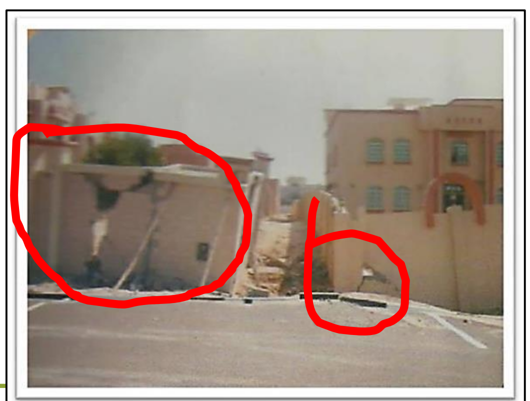


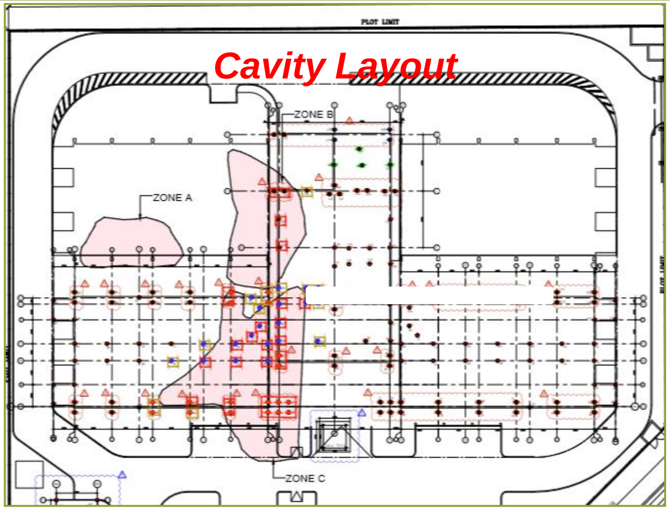
## Foundation solutions for structures on soils with cavities:

1. Piles Foundation
2. Underground Grouting
3. Dynamic Compaction
4. Combining Piling and Grouting

## *Case Study*

# *Five story building on cavity in Abu Dhabi, UAE*

- The selected case study is a project in Khalifa Industrial Zone Abu Dhabi (KIZAD). The project has 3 building with 5 stories. One building located above two cavities was selected to be studied through a numerical investigation.

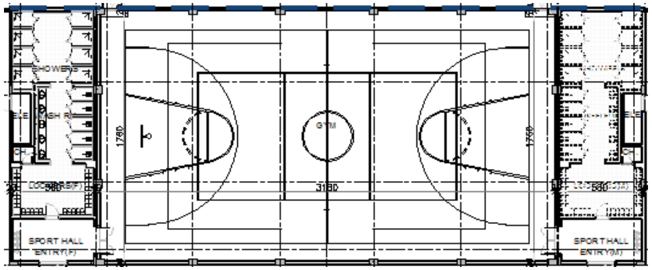


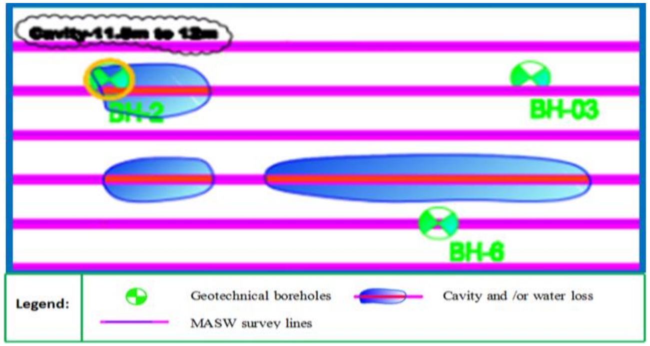

- The selected part of the project has a soil layers arrangement as follow:
    - 0-3 m Sand, 3-7 m Clayey gravel, 7-9.5 m Mudstone, 9.5-14.5 m Gypsum, 14.5-15 m Mudstone

## *Case Study*

# *Indoor Multipurpose Sports Hall in Abu Dhabi, UAE*

- The studied structure is an indoor multipurpose sports hall of a private school located in Shakhbout City in Abu Dhabi.
- The selected part of the project has a soil layers arrangement as follow:
    - Silty Sand, Sand, Gypsum, Mudstone

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# Effect of SSI on Design of Structures

## تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على تصميم الهياكل للمنشات

**SSI effects are categorized according to FEMA, 2009 as:**

1. Inertial interaction effects
2. kinematic interaction effects
3. Soil-foundation flexibility effects

**In the context of engineering analysis and design, these effects are related to:**

1. Foundation stiffness and damping.
2. Variations between foundation input motions and free-field ground motions.
3. Foundation Deformations.

# Effect of SSI on Design of Structures

تأثير الاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على تصميم الهياكل للمنشات

## 1. Foundation stiffness and damping:

- Inertia developed in a vibrating structure gives rise to base shear, moment, and torsion.
- These forces generate displacements and rotations at the soil-foundation interface.
- These displacements and rotations are only possible because of flexibility in the soil-foundation system, which significantly contributes to overall structural flexibility (and increases the building period).
- Moreover, these displacements give rise to energy dissipation via radiation damping and hysteretic soil damping, which can significantly affect overall system damping.
- Since these effects are rooted in structural inertia, they are referred to as ***inertial interaction*** effects.

# Effect of SSI on Design of Structures

تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على تصميم الهياكل للمنشات

**2. Variations between foundation input motions and free-field ground motions:**

Foundation input motions and free-field motions can differ because of:

I. ***Kinematic interaction***, in which stiff foundation elements placed at or below the ground surface cause foundation motions to deviate from free-field motions due to base slab averaging, wave scattering, and embedment effects in the absence of structure and foundation inertia

II. ***Relative displacements and rotations*** between the foundation and the free-field associated with structure and foundation inertia.

**3. Foundation Deformations:**

- Flexural, axial, and shear deformations of structural foundation elements occur as a result of forces and displacements applied by the superstructure and the soil medium.
- These represent the seismic demands for which foundation components should be designed, and they could be significant, especially for flexible foundations such as rafts and piles.

*Case Study*

# *Effect of SSI on Seismic Design of Shear Wall Buildings*

تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على التصميم الزلزالي لجدران القص

## Parameters Considered and Assumptions:

**A** **Level of seismic hazard:**

- High (Vancouver)
- Moderate (Montreal)
- Low (Toronto)

**B** **Shear wall building height:**

- Five-story (low rise building)
- Ten-story (medium rise building)
- Fifteen-story (high rise building)

**C** **Soil type :**

- Bedrock (Class B) ($760<\nu_s\leq1500$)
- Firm ground (Class C) ($360<\nu_s<760$)
- Weak soil (Class D) ($180<\nu_s<360$)

**D** **Foundation representation:**

- Rigid foundation (fixed base)
- Linear (no yield or uplift)
- Nonlinear (yield and uplift are allowed).

**E** **Nonlinear Analysis**

- Nonlinear Static (Dead Load)
- Nonlinear Dynamic (Nonlinear time history analysis)

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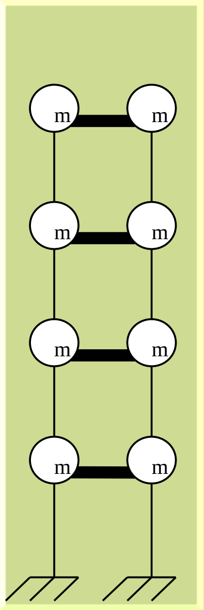
Case Study

# Effect of SSI on Seismic Design of Shear Wall Buildings

تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على التصميم الزلزالي لجدران القص

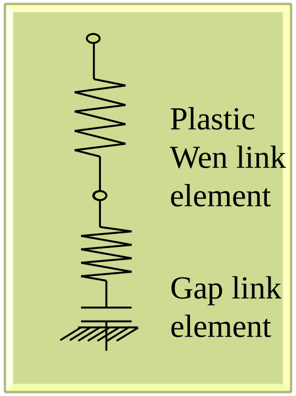
## Assumptions in Building Modeling:

- The length and width of the building are 20 m and 20 m, respectively.
- The typical story height is 3.5 m.
- The mass of each story of the building is lumped at the story level.
- The shear wall is represented by two columns with rigid beams connecting between them.




## Assumptions in Foundation Modeling (Nonlinear):

- The foundation of the building is represented by a rigid slab resting on a Winkler foundation.
- The spring stiffness constant is determined using the static stiffness constant for a rigid plate resting on the surface of an isotropic homogeneous half space soil.
- Each shear wall building is assumed to be resting once on each of the soil classes B through D.

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*Case Study*

# *Effect of SSI on Seismic Design of Shear Wall Buildings*

تأثير الاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على التصميم الزلزالي لجدران القص

## Stage 1: Results for the Effect of SSI on the Seismic Response of Shear walls

### 1. Fundamental period:

- Increased for all studied buildings.
- The increase is more significant for Toronto

### 2. Base shear and overturning moment:

- For Toronto, the reduction was large.
- For Montreal, the reduction was generally small.
- For Vancouver, it slightly increased.

### 3. Top drift and inter-story drift:

- The top and inter-story drifts due to SSI satisfied the NBCC2005 limitations for all cases.
- The top drift increased due to SSI.
- Toronto had in general the highest increase in top drift.
- The inter-story drift increased in the higher stories due to SSI.

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18

## Stage 1: Results for the Effect of SSI on the Seismic Response of Shear walls

### 4. Foundation rotation:

- Increased with the decrease of the soil shear wave velocity for the same building height for all areas.
- In most Cases Toronto had the largest foundation rotation.
- For the five-story buildings resting on soil Class C in Vancouver, a small amount of foundation uplift was observed.

### 5. Foundation sliding:

- Foundation sliding increased with the decrease in the soil shear wave velocity for all cases.
- However, the sliding distances were small
- Sliding distance for Toronto is very small, and  seismic foundation design may be considered too conservative.

*Case Study*

# *Effect of SSI on Seismic Design of Shear Wall Buildings*

تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على التصميم الزلزالي لجدران القص

## Stage 2: Safety Margin in the Foundation Seismic Design of the NBCC2005

- Reduction in base shear is taken as the main indication of the effect of SSI on the safety margin in the NBCC2005 seismic design.
- Only Toronto area had a large reduction in base shear.
- A modification factor of $2/3V_b$ is proposed for the design of foundations for shear wall buildings in Toronto.
- Using this factor will result in more economical foundations for shear wall buildings in Toronto.
- **A dynamic analysis on Toronto models was carried out to verify that:**
  - The modified foundation can withstand the seismic force without collapse ($V_b$ analysis < $2/3V_b$).
  - The new system meets the drift and deflection requirements of the NBCC2005.
  - The foundation will not experience excessive rocking or uplift.

# The influence of SSI on thermal response of structures in hot weather

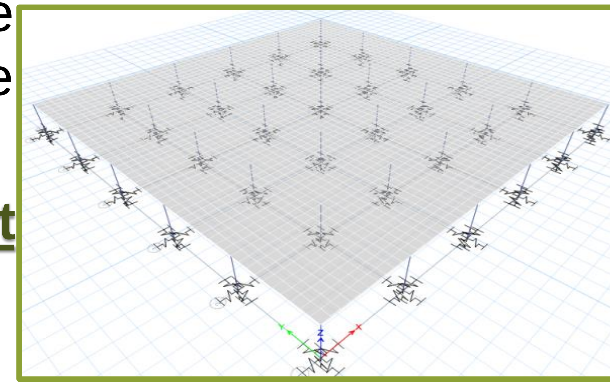
تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على الاستجابة الحرارية للمنشات في الطقس الحار

- UAE is known for its high temperatures especially during the summer period. This high temperature along with the frequent fluctuation in the daily and seasonal temperatures imposes overall structural displacements, and alteration of stresses in concrete elements.
- To avoid this problem, expansion joints should be provided. However, as per the buildings functions, joint-less buildings are usually the preferred option. When using this option the structural engineer has to consider the effects of thermal loads, creep and shrinkage in the design.
- Clear rules and standards have to be provided to define the joints spacing's allowed length in addition to thermal study procedures. Unfortunately this issue is not defined clearly in buildings standards and regulations used in UAE.

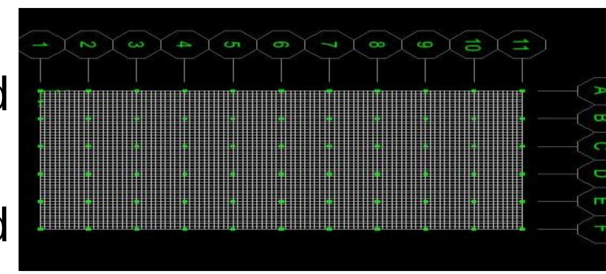
## Numerical Models:

## النماذج العددية:

- Five hundred – forty four (544 ) one-story reinforce concrete frame building ETAB models were generated in this study.



- **The models were divided into four different groups:**
  - The first group with columns fixed supports
  - The second group with column hinged supports
  - The third group with columns supported by isolated footings (3X3 $m^2$) resting on Class B soil
  - The fourth group with columns supported by isolated footings (3X3 $m^2$) resting on Class D soil.




- Each group is comprised of one hundred-thirty six (136) ETAB models half of them analyzed with linear concrete properties and fixed temperature of T = 40°C and another half with nonlinear concrete properties with time dependent temperature properties.

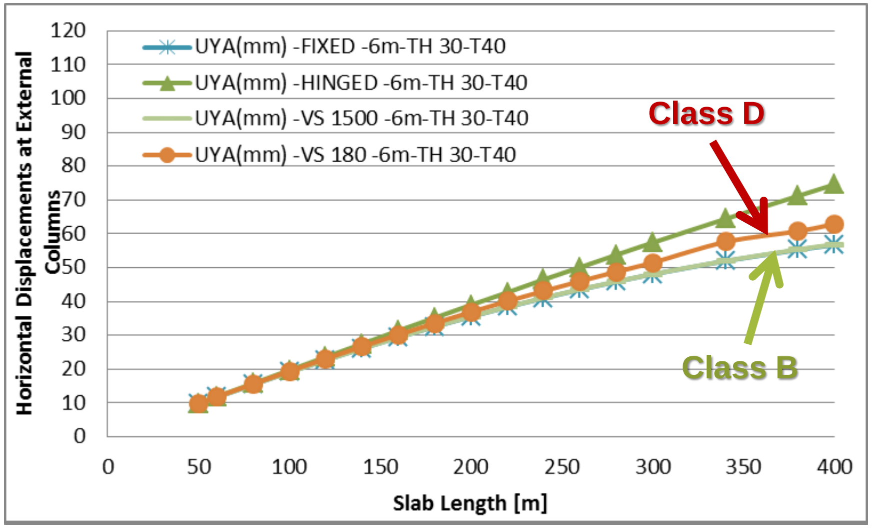
**Case Study**

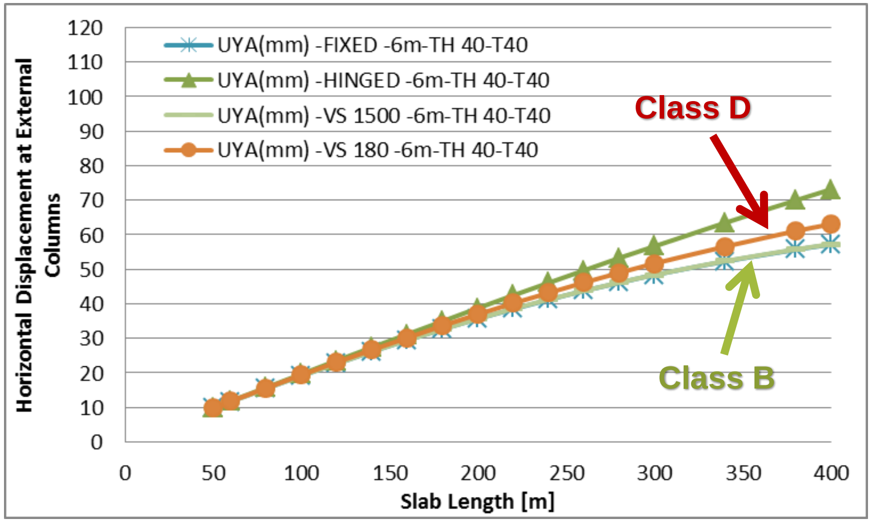
## *Effect of SSI on Response of One-Story Frame Buildings under Thermal Loads*

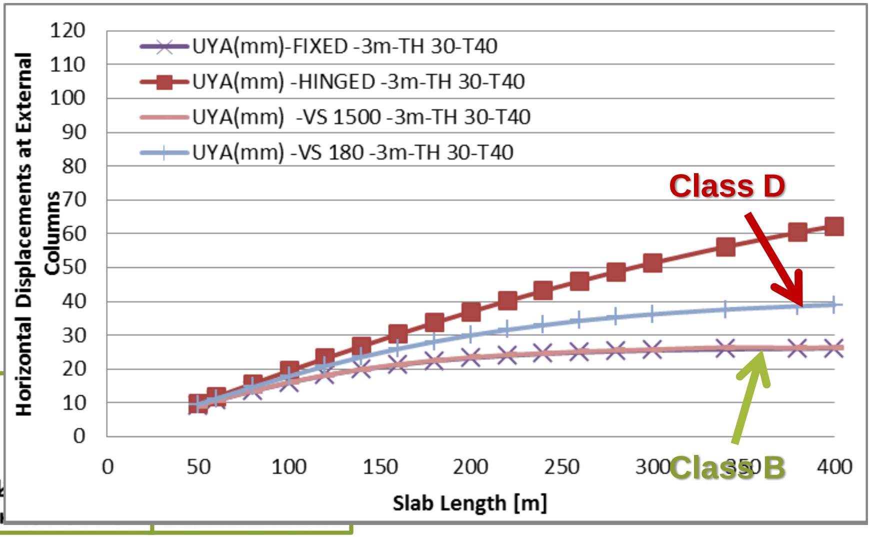
تأثيرالاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على الاستجابة الحرارية لمبنى من طابق واحد

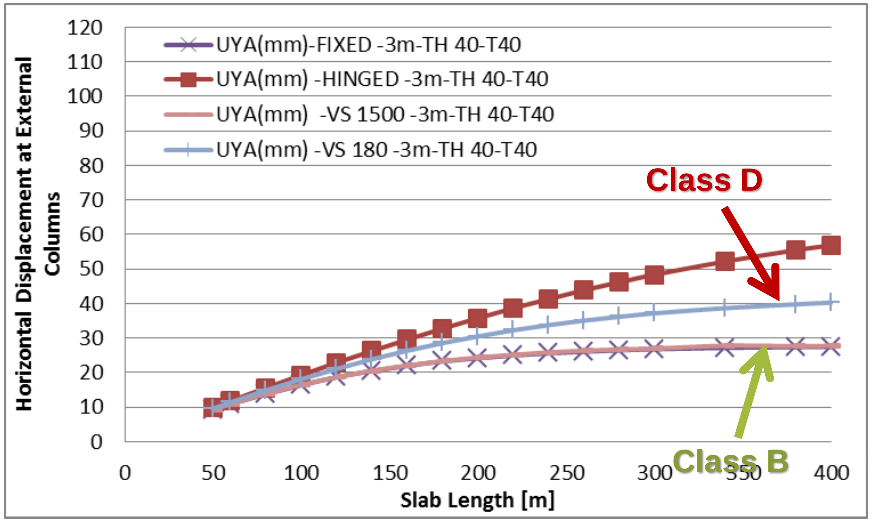
# Horizontal Displacement at External Columns

# الازاحه الافقيه في الاعمده الخارجية



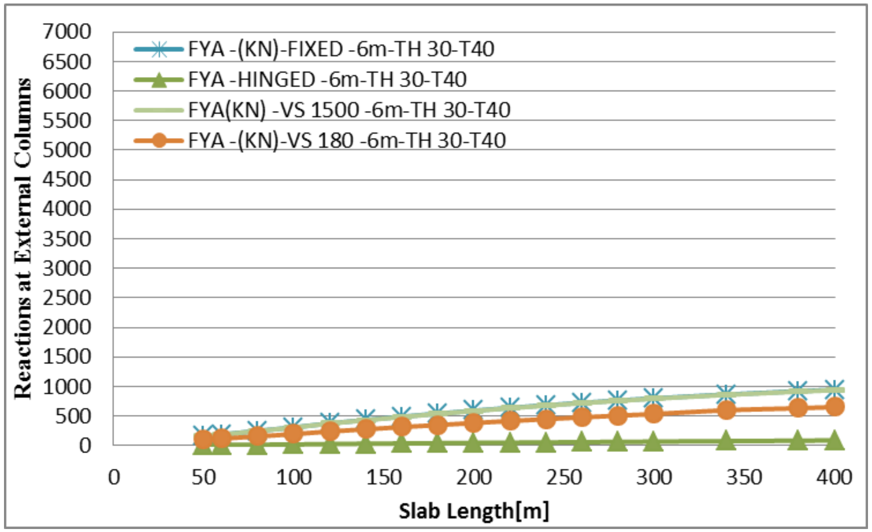
**Case Study**

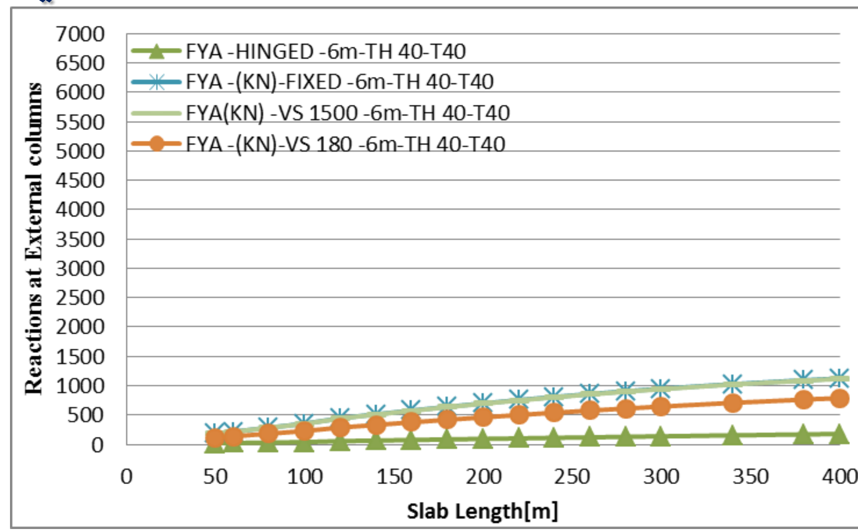
## Effect of SSI on Response of One-Story Frame Buildings under Thermal Loads

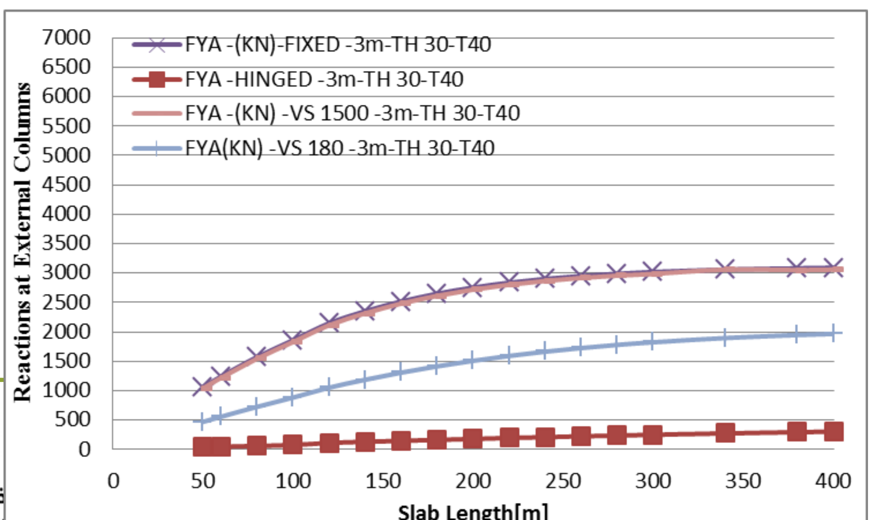
## تأثير الاخذ بإعتبارات التفاعل الجيوتكنيكي بين التربة و المنشات على الاستجابة الحرارية لمبنى من طابق واحد

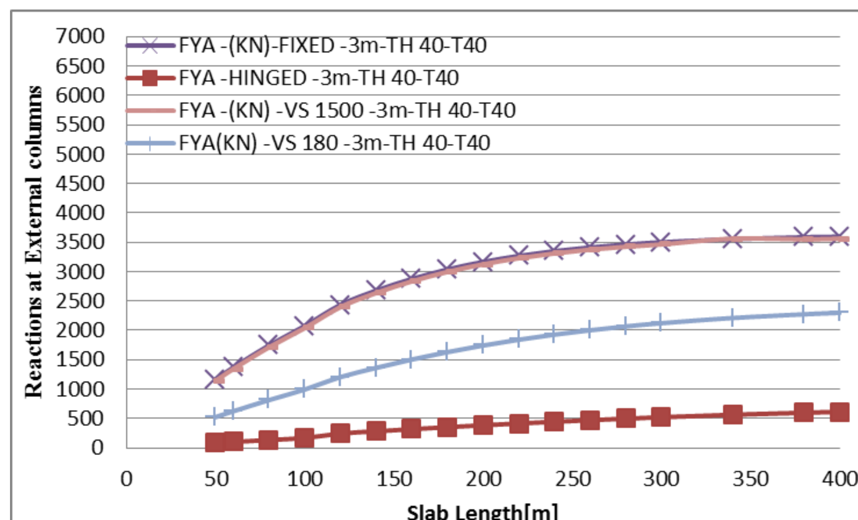
# Reactions at External Columns

# ردود الفعل في الاعمده الخارجية



| Conclusions and Recommendations | الاستنتاجات و التوصيات |
|---|---|
| • Cracks due to geotechnical reasons can be categorized as cracks in block work and cracks in concrete elements. | • يمكن تصنيف التشققات الناجمة عن أسباب جيوتكنيكية الى تشققات في أعمال البلوك و تشققات في العناصر الخرسانية. |
| • Foundation settlement is the main geotechnical reason for developing cracks in buildings. | • الهبوطات في الأساسات هي المسبب الجيوتكنيكي الرئيسي لتكون الشقوق في المباني. |
| • In some cases not accounting for the effect of Soil Structure Interaction will lead to overlooking the foundation rock effect that will lead to inappropriate structural design and by its tour to cracking in buildings. | • في بعض الحالات يؤدي عدم الأخذ بالإعتبارات الجيوتكتيكية على تصميم الهياكل للمنشات إلى عدم أخذ التأرجح في الأساسات بعين الاعتبارو بدوره إلى تصميم هيكلي غير ملائم مما يؤدي ألى تصدعات في المباني. |
| • Proper geotechnical and geophysical tests should be conducted on soils in areas prone to cavity developments to properly design the foundation to avoid cracks in buildings. | • يجب إجراء اختبارات جيوتكنيكية وجيوفيزيائية مكثفة على التربة في المناطق المعرضة لتطوُّرات التكهفات الجوفية من أجل تصميم الأساسات بشكل صحيح لتجنب التصدعات في المباني. |
| • Extra caution should be taken to avoid foundation settlement to eliminate cracking in buildings due to geological reasons. | • يجب الأخذ بالاحترازات اللازمة لتجنب الهبوطات في الأساسات من أجل تفادي التشققات في المباني لأسباب جيوتكنيكية. |

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# شكرا لحسن استماعكم

# Thank you for attending

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