Concrete consolidation in the 21st century

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ACI Committee 309

Consolidation: A little more than just putting a vibrator in concrete.

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Introduction

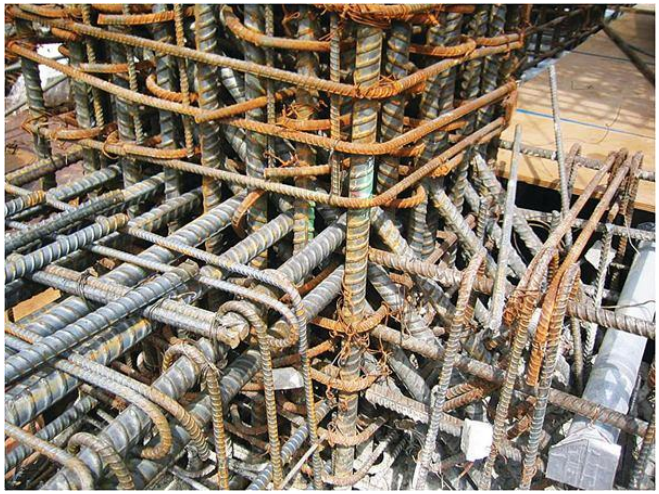
- Consolidation of concrete is essential for structural performance, durability and esthetics of the built structure

- Poor consolidation can lead to…
  - Variable and heterogeneous concrete
  - Structural Inadequacy
  - Inadequate bond with reinforcing bars and embeds
  - Safety issues with PT around anchor zones
  - Significant surface defects, i.e. honeycombing, bugholes
  - Costly, difficult and time consuming remedial work

Causes of poor consolidation…

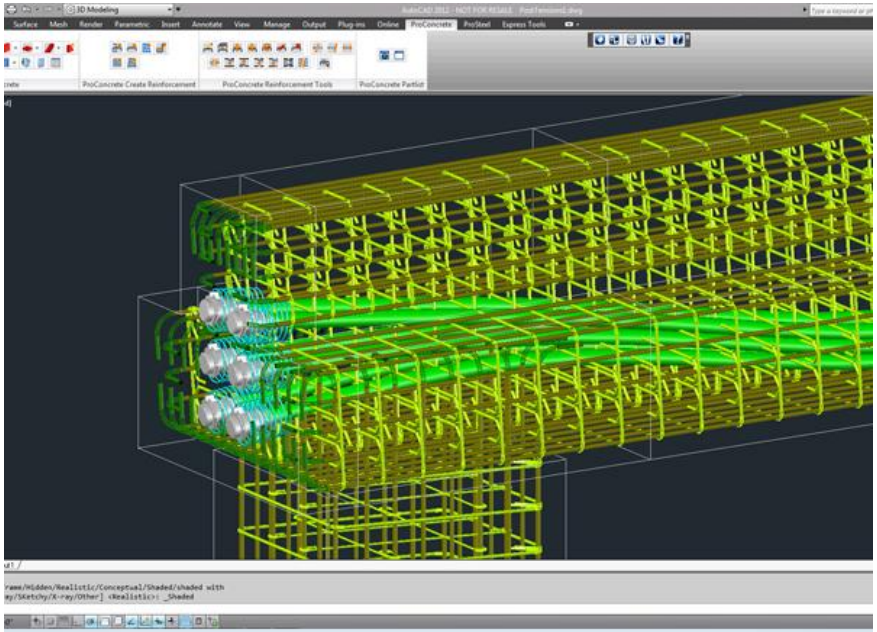
Reinforcing congestion

- Clear space between rebar is less than 1 1/3 times the course aggregate size
- Condition likely occurs at splice zones, beam-column connections, PT anchor zones
- Multiple layers of reinforcing bars when the bars in the lower layers are not directly below those in the upper layers.



Causes of poor consolidation…

PT anchors, Embeds, boxouts
- Need add'l rebar
- Create/make congestion issues worse



Causes of poor consolidation…

- Type of Element
  - Tall thin elements
  - Corbels and haunches
  - Battered form faces or counterforts restricts concrete placement, vibrator access, and air migration during vibration
- Formwork
  - Surface texture
  - Shape, type, and orientation can restrict concrete
  - Used or poorly oiled wood forms are more likely to cause problems than steel or plastic-lined forms .
  - Leaky form joints

Causes of poor consolidation…

- Mix Design
  - Too stiff of mix, loss of slump
  - Aggregate size too large for rebar spacing
  - Segregation
- Placement
  - Too great free fall, >6ft
  - For tall narrow wall pours
- Vibration
  - Inadequate vibration
  - Poor vibration technique
  - Inadequate/poorly trained personnel

Poor consolidation…

Poor consolidation…

Poor consolidation…

Poor consolidation…

Poor consolidation…

- Age of form…
  - Left side: old form
  - Right side: new form

Poor consolidation…

- Leakage of forms

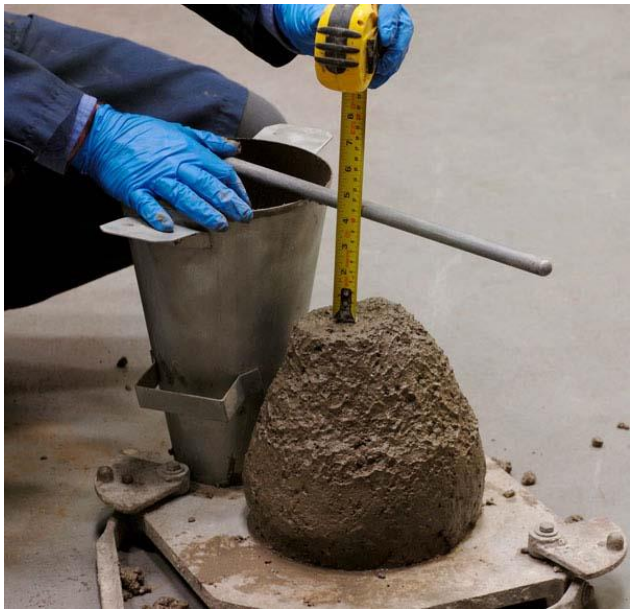
Ingredients for good consolidation

- Pre-pour planning!
- Examine proposed reinforcing & embeds
  - Suggest detailing changes as required
  - Utilize terminators
  - Use fewer, larger bar size
  - Change rebar from GR60 to GR80
  - Mechanical couplers
  - Increase member size
  - Use single larger boxout in lieu of multiple closely spaced smaller boxouts

Ingredients for good consolidation

Review Mix Design

- Normal, High Slump, or SCC?
- Examine aggregate size
- Workability
- Mix stability
- SCM
- Admixtures
- QA/QC on site



Ingredients for good consolidation

- Formwork
  - Eliminate, reduce number of tie rods
  - Provide side chutes & access hatches for placement & vibration
  - Use steel or fiberglass forms in lieu of higher friction wood forms
  - Ensure form surfaces are in good shape, repair/replace as rqd
  - Ensure form tightness at joints and corners to prevent leakage of cement paste
  - Adequately and evenly apply form release oil

Ingredients for good consolidation

Good Vibrations!

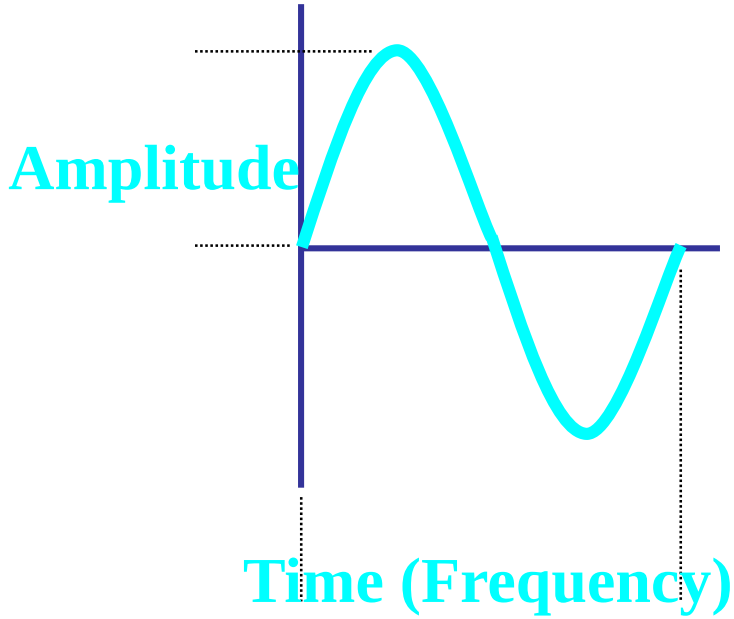
- A series of rapid compressive impulses
- Reduces the surface friction between particles
- Vibration energy moves the particles
  - –Slumping
- The movement releases trapped air
  - –Deaeration
- Slumping and deaeration happen simultaneously from the surface of the vibrator outward

Types of Concrete Vibrators

- External vibrators
  - Vibrates entire mass - forms and concrete
- Internal vibrators
  - Apply energy directly to the concrete
  - Depends upon skill of operator
  - Head, motor, and shaft style
  - Motor-in-head style

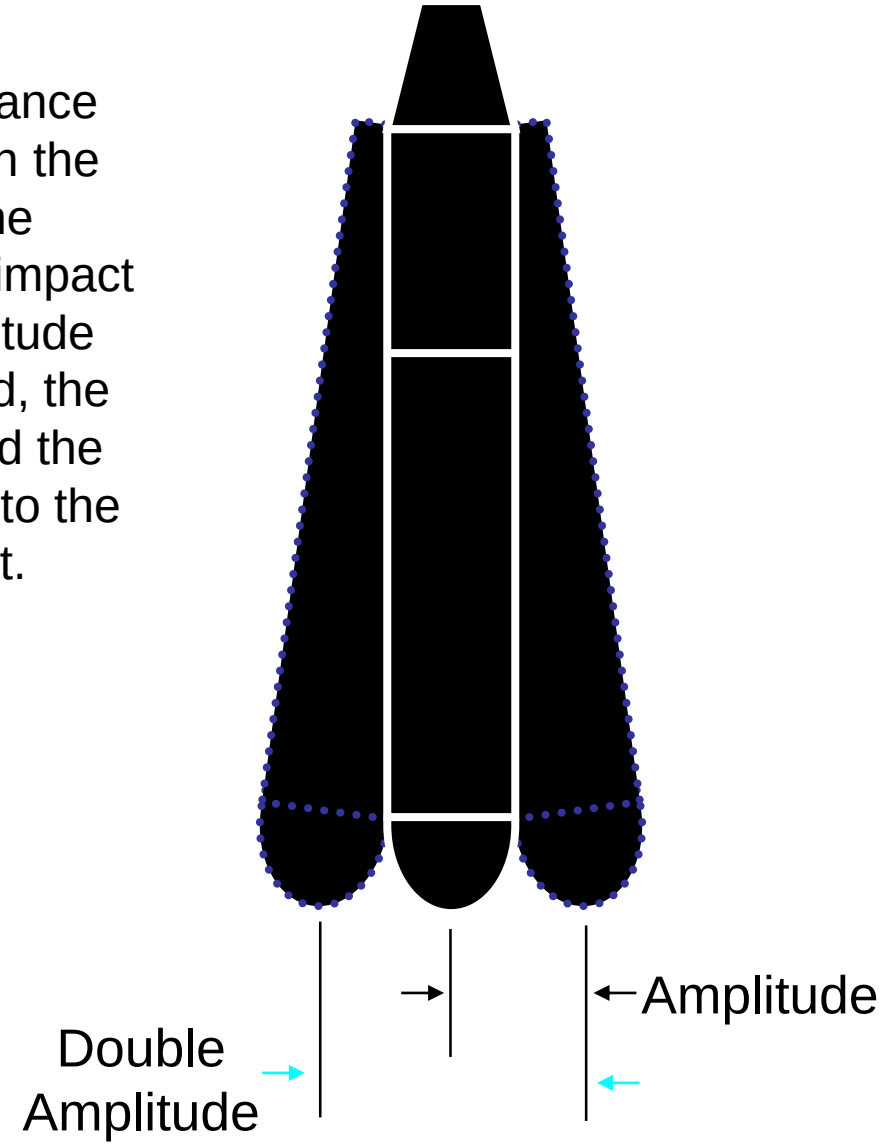
Vibrator Characteristics

- Frequency
  - The number of vibrations per minute (vpm)
  - The higher the frequency, the better
- Amplitude
  - The distance the vibrator moves around the neutral axis



Vibrator Characteristics: Amplitude

Amplitude is the measured distance from the neutral axis about which the vibrator moves. The larger the amplitude, the greater the kick or impact against the concrete. The amplitude depends on the mass of the head, the mass of the eccentric weight, and the radius from the center of rotation to the center of gravity of the weight.



Vibrator Characteristics: Frequency

- Frequency is the number of times a vibrator head moves from side to side in one minute. It is expressed in vibrations per minute or VPM.
- Fine particles respond to high frequency vibration
- Select high frequency vibrators because:
  - The largest percentage of entrapped air is found in the fine particles
  - Will not displace or segregate coarse aggregate
  - Coats coarse aggregate with cementitious paste
  - Fines move independently making the mix flowable

Vibrator Characteristics, cont.

- Centrifugal force
  - The amount of energy produced by the rotating weight
- Size
  - The physical dimensions of the vibrator
  - The larger the vibrator, the larger the effective diameter

Using External Vibrators

- Directly mounted to formwork
- Supplement Internal Vibration
- Often used on architectural concrete
- High frequency, low amplitude works best

Using the Internal Vibrator

- As the concrete vibrator is inserted
  - mounds of concrete flatten and level
  - the concrete flows to forms edge and around embedded steel
  - expels some of the entrapped air
- A systematic pattern of vibration may now begin

Using the Internal Vibrator

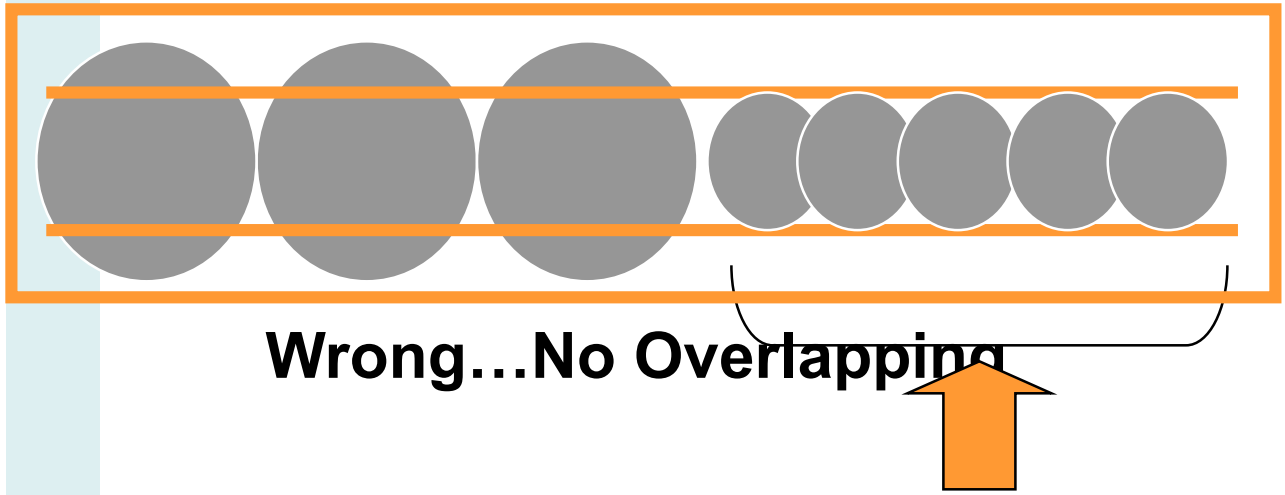
- Proper Handling
  - submerge vibrators quickly and vertically
  - hold for 5-15 seconds to blend layers
  - withdraw at one inch per second
    - never more than 2” per second
    - this is the speed at which air rises through concrete
- If a hole left by vibrator does not close:
  - mix design is too stiff for internal vibration
  - vibrator frequency is incorrect

Vibrator Sizing

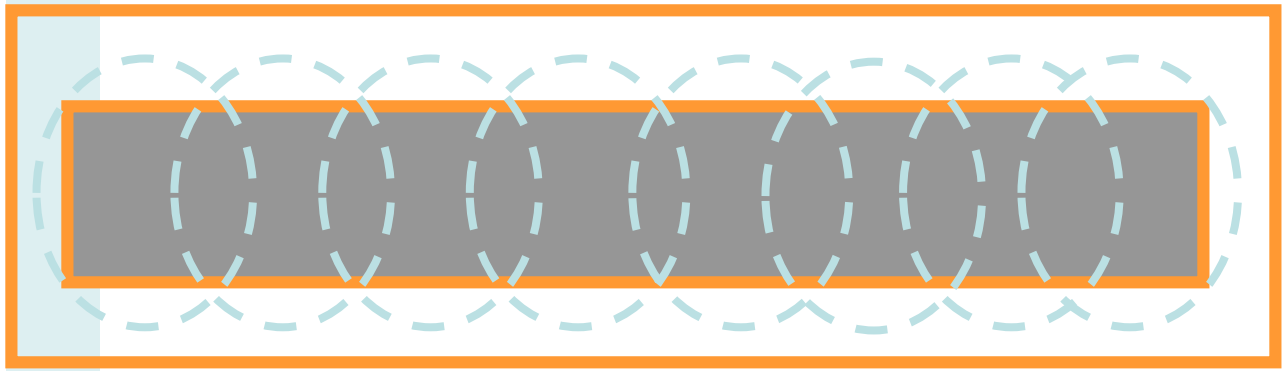
- Make sure the head is large enough
  - Based on effective compaction diameter
  - Divide effective diameter by 2
  - Wall section should not be less than this
  - Example : 24 inch eff. dia. / 2 = 12 in.
  - Do not use this head on less than 12 in. wall
- Make sure shaft is long enough
  - Most air is trapped at bottom of form

Vibrator Sizing…Patterns

Vibrator Sizing…Patterns



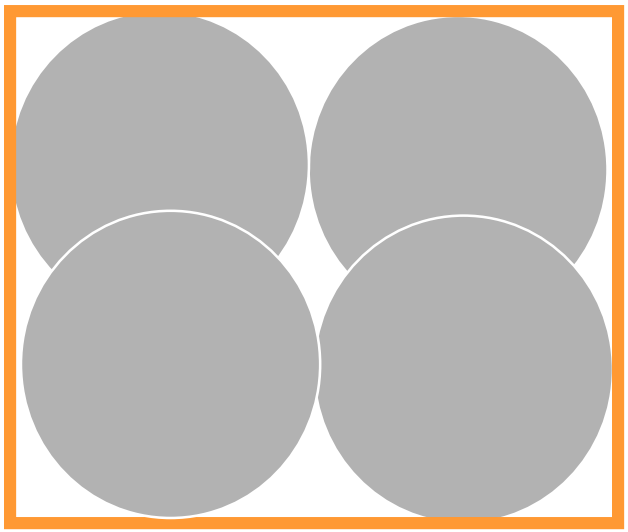
Wrong…No Overlapping



Correct…Patterns Overlap

As a general rule, multiply the head diameter by ten to find the approximate area of influence when it is otherwise unknown.

Vibrator Sizing…Patterns



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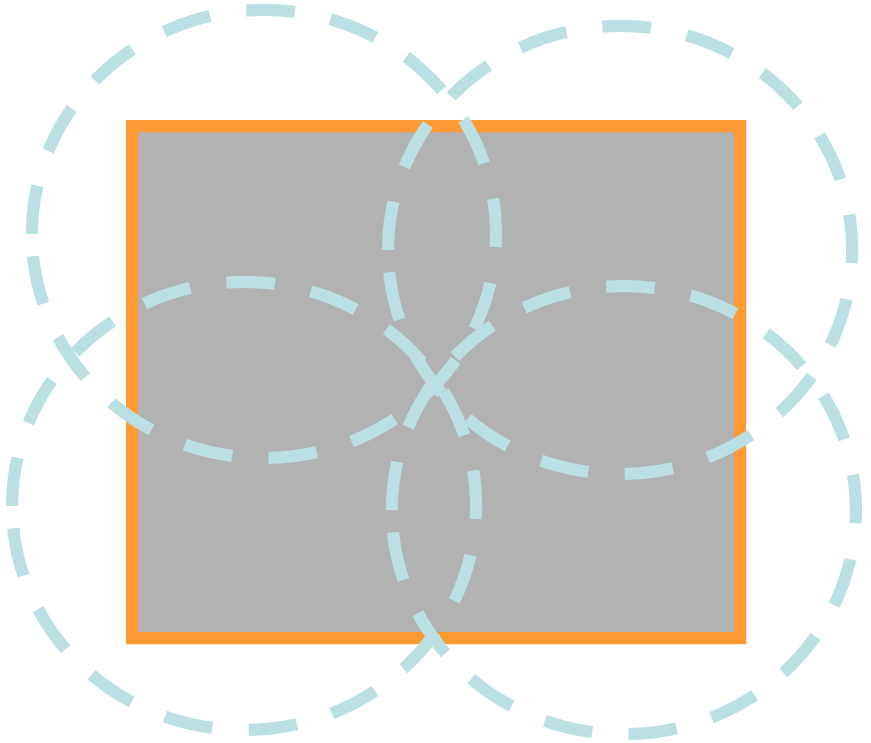

Correct…Patterns Overlap

Vibrator Application

- Advantages of Internal Vibrators:
  - Applies energy directly to the mix
  - Can meet many applications due to head and shaft combinations
  - Very portable on jobsite

Handling Internal Vibrators

- Avoid vibrating too fast
  - Raise at **1 inch** per second
  - **This is the speed air rises in concrete**
- Avoid vibrating in irregular patterns
  - Patterns must overlap 1.5 times the radius of action
  - Ensures that all concrete is consolidated
- ACI 309R states max. lift does not exceed 20 inches
  - Penetrate the last layer by a minimum of 6 inches
  - Stitch layers together for 5-15 seconds before slowly withdrawing

Handling Internal Vibrators, cont.

- Avoid touching the form skin
  - Leaves stinger marks
- Avoid vibrating the rebar
  - Head can become stuck
  - Can damage rebar ties
- Avoid using vibrator to move concrete
  - The vibrator is not a “Power Shovel”
  - Causes segregation of aggregate

Vibration Problems

Undervibration may cause:

- Sand streaks on the face of the finished product
- Failure to remove entrapped air
- Honeycombing and bug holes
- Failure to knit lifts together, or cold joints

Overvibration may cause:

- Aggregate segregation
- Sand streaks on the finished surface
- Deflection or blowout of forms
- Loss of entrained air if overvibrated excessively

Too much vibration is preferable to not enough, and it should generally not cause concern unless the concrete in question is of high slump and poorly proportioned

Conclusions

- Pre-pour planning critical
- Communication is the key to success
- Good consolidation is both an art & science. Skilled personnel rqd.

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QUESTIONS?

THANK YOU!!