#### Singapore – a new downtown Steel Innovations 2015 - SCNZ

04 September 2015 Brendon McNiven, Principal, Buildings



Laos Vietnam Thailand Cambodia Philippines Malaysia Brunei Singapore PNG Indonesia Australia





### Where we are in South East Asia

#### Singapore An artificial diamond created by stress Indonesia Malaysia Singapore 1,900,000 sq km • 329,847 sq km • 710 sq km •

• 5.0 m people

27.7 m people

•

• 230 m people

#### Singapore Has 3 Resources Location, Land and People

#### Maximize Land Utilization

Land = 710.4 sq km (22% reclaimed) People = 5.0m (3.3m citizens)



8th Jul 2010

**EDB** (Economic Development)

URA (Planning)

STB (Tourism)

LTA (Transport)

SLA (Land)

Singapore

NParks (Parks and Trees)

KALLANG BASIN

Existing Marina Promenade

GARDEN AT 15 ha 

> Gardens by the Bay East

> > GARDEN AT MARINA EAST 32 ha

> > > Currently undeveloped secondary forested area

OPIDIOL KG

**MOTOR** 

.............

MARINA CHANNEL

Bay South smaller ponds at Marina South Promenade

Existing Marina Padang

Existing Marina City Park/ GARDEN AT MARINA SOUTH 54 ha

lens by the **H** 

SingaporeFlyer

Existing Marina South F&B and Entertainment Zone

SINGAPORE

Double

Downtown MRT Line

Bay Promenade

MARINA BAMarina Bay Sands

Existing CBD (Shonton Way









# The Singapore Flyer

Tourse a

KALLANG BASIN

Existing Marina Promenade

GARDEN AT MARINA CENTRE

**Singapore**Flyer

MARINA BAY

Existing CBD (Shenton Way) 1 -1

Currently undeveloped secondary forested area

32 ha

MARINA CHANNEL

2 smaller ponds at Marina South Promenade

GARDEN AT MARINA EAST

Existing Marina Padang

Existing Marina City Park GARDEN AT MARINA SOUTH 54 ha

Existing Marina South F&B and Entertainment Zone



Private Developer led (Melchers Pty Ltd)

Government supported (STB/SLA)

\$200M

# History & Evolution



#### Millennium Wheel Initial idea (architect led)



# Millennium Wheel

Initial idea (structural feedback)



# **Competition Entry**



### **Design Evolution**

# $E_{\text{FFICIENCY}} \Pi = \frac{OUTPUT}{\text{INPUT}}$

MEASURE	INPUT	OUTPUT	MEASURE
WEIGHT COST \$ COST ENV.	MATERIALS	AESTHETILS ON ITS OWN AS A PART OF THE ENVIRON,	APPEARANCE / PERLEPTION
COST \$	DESIGN	FUNCTION - PRIME (IN SERVICE)	(OPERATING COST No. PEOPLE PEOPLE HAPPINESS
COST \$ }	ENERCY	- SECONDARY (AFTER SERVICE)	{ RE-USABILITY { RESALE VALUE
		EXTERNAL EFFECTS	
		- IMMEDIATE ENVIRON.	DAMAGE TO PARK
		- BY PRODUCTS OF CONSTRUCTION	{ POLLUTION WASTE
		COLIETY	(TOUDDIEDO)

### **Design Evolution**



### Tension Wheels Superposition



### Tension Wheels Understanding cause & effect



### Millennium Wheel

Cables act to provide restraint to rim both laterally and torsionally (resisting applied loads and controlling rim compression buckling):

135m diam : 64 + 16 = 80 Cables:

- Lateral/Radial restraint & stiffness
- Torsional buckling restraint





# Singapore Flyer

#### 150m diam : 112 Cables performing both:

- Lateral/Radial restraint & Stiffness
- Torsional buckling restraint





**Engineering-led design** The final rim structure for the Singapore flyer was approximately 15% larger than its predecessor the London Eye, and used approximately 15% less steel.

# Las Vegas High Roller

155m diam : 112 cables

#### **Cables provide:**

• Lateral/Radial restraint & Stiffness

#### Annulus action in rim provides:

• Torsional stiffness / Stability





# Erection



SINGAPOLO PLYON ERECTION OPTION 2 SHEET ' SK/JEB/188203/2



(1) Installed rim segments are jacked in for installation of subsequent segment.

② This process is repeated with installation of all segments









**(1)** Temporary struts installed every 5<sup>th</sup> segment.

② Tie-member used to prevent rim buckling.

























Completion of rim installation.



Laser technology was used in ensuring acceptable erection tolerances and in measuring the tensions in the prestressed spoke cables.


# Marina Bay Sands <sup>®</sup> Integrated Resort

KALLANG BASIN

Existing Marina Promenade

GARDEN AT 15 ha 

> ingaporeFl ver

SINGAPORE

Existing CBD (Shenton Way

MARINA BAY

Mari Bay S and

Existing Marina Padang

Existing Marina City Park/ GARDEN AT MARINA SOUTH 54 ha

Existing Marina South F&B and Entertainment Zone

GARDEN AT MARINA EAST

MARINA CHANNEL

2 smaller ponds at Marina South Promenade

32 ha

Currently undeveloped secondary forested area

Government Land & Gaming License release 3 month competition

(URA)

awarded Aug 2006

completed Feb 2011

US\$5.5b







340m deck structure sitting on top of 3 x 55 storey hotel towers...

#### with a 65m cantilever at one end...



B NS/11

12

#### ...built on up to 35m of reclaimed land/marine clay







#### **Hotel Superstructure**

#### Tower 1 – Wall Elevation

- ► 600mm thick typical RC shearwalls
- Concrete grade = 60 N/mm<sup>2</sup> (lower)
   50 N/mm<sup>2</sup> (upper)
- Floor concrete grade =  $40 \text{ N/mm}^2$
- ► Height to L55 = 176.8 m
- Height to Skypark deck (L56) = 190 m
- ► Height to Skypark roof (L58) = 199.1 m





# **Deflection Studies**

#### Location of Interest

- 1. Angular rotation at top of tower
- 2. Maximum deflection on elevation
- 3. Differential settlement between straight and curved wall
- 4. Differential settlement between adjacent wall bays



Fig 1 Deflection Shape of Tower 1

## **Deflection Studies**

1. Angular rotation at top of tower

		Short-term	Long-term	
CASE		δ <sub>A</sub> - δ <sub>B</sub> (mm)	δ <sub>A</sub> - δ <sub>B</sub> (mm)	
(i)	DL+SDL+LL (w/ creep & shrinkage effect)	57	100	
(ñ)	100% elastic DL	26	26	
(iii)	Net Deflection [(i) - (ii)]	31 (0 = L/968)	74 (θ = L/405)	
(îV)	Net Deflection x15% contingency to account for staged construction effect [(iii) x 1,15]	36 (0 = L/833)	85 (θ = L/353)	



#### Fig 3 Item 1 --- Angular Rotation at Top of Hotel Tower





Sloping Tower

**Déath** Loades













#### **Cantilever Construction**





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## **Cantilever Construction**





Segment 5 (24<sup>th</sup> December 2009)

# SANDS SKYPARK



People - Testing under real excitation

INCOMENTAL PROPERTY.

groups of up to 160 people









## Findings



#### **Skypark Fast Facts:**

- Skypark length
- Steel Tonnage
- Cantilever Length
- Cantilever Weight

100

340m 7,700t 65m 3,500t

Allinnum



Singapore Sports Hub
KALLANG BASIN

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GARDEN AT 15 ha 

> ingaporeFl ver

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GARDEN AT MARINA EAST 32 ha

Currently undeveloped secondary forested area

2 smaller ponds at Marina South Promenade

Existing CBD (Shenton Way)

Government led PPP (to replace old National Stadium)

DSPL / HSBC / Arup & DPA

\$1.2B















#### 312m span dome











2 halves of Movable Roof in open position (secondary trusses under not shown for clarity)

Column pairs supporting Ring Beam & acting in portal action.

Thrust Block node

supporting roof on

Ring

Beam

Segment of Level 3 Ring Beam





#### **Fatigue Considerations**

12,800 cycles over 50 years (FOS of 2 on design)Local fatigue from bogie movement







## Connection Break up

Group 1 (55%)



Single chord (457 or 355.6 CHS) +bracing

Group 2 (35%)



457 chord with 355.6 secondary chord or X-brace +bracing

Group 2 (10%)





At truss junctions many intersecting chords and bracing



## non-FEA CHS connection design

#### Research

- CIDECT
- Eurocode 3
- American Petroleum Institute (API)
- American Welding Standard (AWS)
- Plus many papers





Chord Shear

Punching Shear

**Brace Buckling** 



Failure mechanisms

**Design methodology** 



Figure 2.18—Detail of Overlapping Joint (see 2.25.1.6)



Chard Danding Callure Modes for KK-Joints: (a)

#### Finite element modeling of complex connections







## BIM on SSH

Combined model of structure, architecture and MEP ready to use for coordination, take-offs, visualisations, walk-throughs etc



# Design Coordination

Services are especially difficult to visualise as the only views the architectural and structural teams traditionally see during the critical stages of the co-ordination process are the single line diagrammes. BIM makes problems such as low-headroom much more obvious.



## Design Coordination

Arup Scope:

Sports venue design, civil, structural, fire and maritime engineering, acoustics, security and risk consulting, moving structures, geotechnics, feature lighting design, sports lighting, pedestrian modelling and turf consulting **Fast Facts:** 

- 312m dia dome roof 85m above pitch
- **8000t of CHS steelwork**
- Over 20,000 steel elements
- 6 analysis models to cover different movable roof configurations
- Each analysis model with 1,5000 combination cases
- 2,500 fixed roof +1,000 movable roof +1,750 louvre connections





- Reconfiguration Athletics to Football in 48hrs













# ARUP