REPORT ON SANITARY 'HYDRAULIC JUMP' PHENOMENA IN THE PETRONAS TWIN TOWERS (TOWER 1 & TOWER 2), LOWER ZONE LEVEL (9th TO 15th FLOOR) AT THE MALE AND FEMALE TOILETS

Studor comments on this proposal, the intention of the comments is to highlight difference and recommendation using current research and international practise for fixing high rise buildings and in particular the issues that we have initially observed in the towers.

1.0 OBJECTIVE

The objective of this report is to ascertain the sanitary "hydraulic jump' phenomena in the Petronas Twin Towers (Tower 1 and Tower 2), Lower Zone (9th floor to 15th floor) at the Male and Female toilets. KTA Tenaga (KTAT) Sdn Bhd to forward a remedial proposal to encounter this problem.

Studor- While the perceived objective of a drainage system may be the removal of waste to the sewer, fundamentally an unsteady free surface liquid flow operation, the prevention of cross-contamination is an absolute necessity to protect against both infection spread and odour ingress. Therefore the analysis of the building drainage and vent system operation must emphasise the mechanism of entrainment that accompany the unsteady liquid flows through the network and determine both the air pressure regime within the system and the probability of a appliance trap seal depletion and the cross- contamination. Dyteqta will be used to establish this before any recommendations of a remedy can be considered

Studor- The issues of that are occurring in the drainage system are occurring due to transient pressure problems due to a undersized drainage vent system and also due to the size of the drainage stacks causing constant positive pressure throughout the whole system. The hydraulic jump is in part only part of the issue that are affecting the water trap seals. Dyteqta-Studor proposal is that the failing system as a whole will be first analysed using the latest sonar monitoring system to fully monitor when and why the trap seals in the system are failing. From the analysis a remedies can be proposed to solve the issues within the buildings, this will most likely be an active venting solution or a passive venting solution (as this current proposal is trying to do in part)

2.0 BACKGROUND

The sanitary 'hydraulic jump' phenomena had been sighted initially in the Petronas Twin Towers (Tower 1 and Tower 2), Lower Zone (9th Floor to 15th Floor) at the Male and Female toilets during the early stages of the operation, but its occurrence were less frequent and further apart.

In 2002, the frequency of this phenomenon became more apparent in the lower zone of the Male and Female toilets, due to the increased usage especially during peak periods.

Studor- In the experience of Studor, high rise buildings above 40 floors start to experience problems within their systems when the building occupancy starts to exceed 70% or when buildings are built around the original buildings and city sewers become filled to a greater degree and there for have less capacity to relive the air in the system from the buildings discharging into them. It must be noted that a building drainage system moves 80% air to 20% water/waste and if this air cannot flow out of the building into the sewer it will reflect back up the building. The buildings venting solution must be designed to deal with this.

3.0 GENERAL

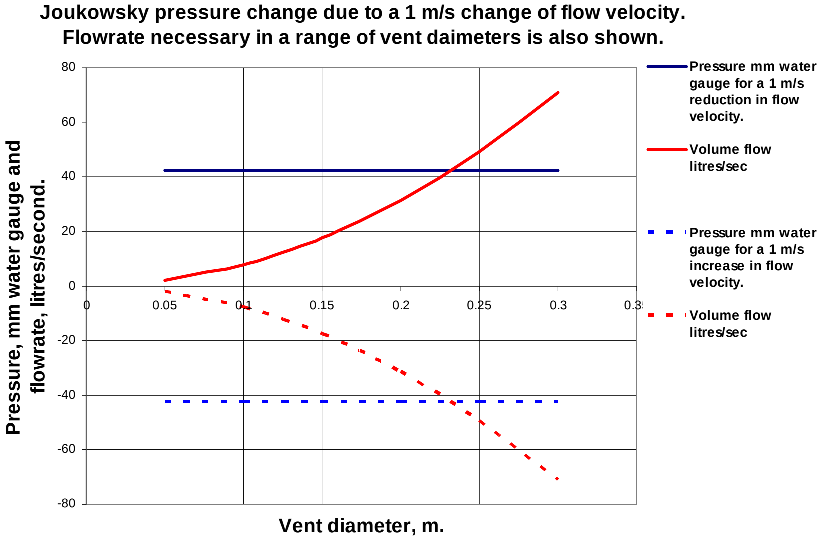
A Sanitary drainage system generally consists of horizontal branches, vertical stacks and building drain outlets to the point of discharge.

3.1 Sanitary Design Practices

A sanitary pipework system shall generally be designed and installed to:

1) Provide efficient conveyance of discharge (soil and waste) from sanitary ware, and wash-down facilities, to enable the correct function of each appliance
2) Prevent the transmission of foul air into the building

Studor-This is achieved by using water trap seals. It is known as a fact that if the system pressures exceed 400Pa (40mmWG) water trap seals will be breeched either by negative pressure or positive pressure.



3) Minimize the frequency of any blockage.

Sanitary discharge pipework should therefore be kept as short as possible, with few bends and with adequate gradient.

3.2 Ventilating Pipe

The purpose of a ventilating pipe is to maintain equilibrium of pressure within the sanitary discharge system to prevent the depletion of trap seals by siphonage, reduce backpressure and to promote the rapid and silent flow of wastes. Pressure and vacuum surges cause objectionable movement of water in the water closet traps as well as affect the trap seals in the sanitary appliances.

The capacity of the vent pipe is governed by the system's ability to manage the incoming air in a manner that pressure excursions, positive and negative will be within the limits of plus or minus one-inch (25.4mm) column of water from atmospheric pressure.

The top of the ventilating stack may connect to the discharge stack above the spill over level of the highest appliance, fitted either with an air admittance valve, or extended outside the building to form a vent terminal.

Studor- Why is there a need to vent the drainage system?

If we do not protect the water trap seals, smells and disease can enter into our living or surrounding spaces. Protection may be provided by using the outdated and limited researched pipe network system (passive system) or the ***STUDOR*** *system (an active system providing the relief at the Point Of Need (PON).*

The conventional thinking in drainage venting is to deal with the negative pressure. This originates from the original studies carried out by Hunter in the 1920 (Hunter's Curve), which only looked at steady state systems. The established thinking is water trap seals are depleted due to nhsiphonic action. The most common causes are Self Siphonage and Induced Siphonage.

A negative pressure transient occurs when there is a discharge of fixtures to which the trap seal is connected. This can have the effect of reducing the trap seal (or pulling the trap). This occurs as the momentum acquired by the waste passes through the fixture and down the trap seal. This momentum is transferred directly into the trap seal and trap seal loss occurs. This is commonly known as 'Self Siphonage'.

Other fixtures discharging in the building can also affect the trap seal. This occurs when there is a pressure fluctuation caused by a discharge of another fixture in the system other than the fixture to which the trap is connected. This is commonly known as 'Induced Siphonage', which is very common in multi-storey buildings. *Plumbing Regulations call for the water trap seal on sanitary fixtures to be maintained at all times. This is accomplished by the introduction of atmospheric air pressure into the plumbing drainage system.*

The venting component of a plumbing drainage system is broken down into:

Trap venting *Venting of a single fixture.*

Group venting *Venting of a group of fixtures, using one vent on the wet side of the last fixture.*

***Branch venting**: Ventilating pipe connected to a branch discharge pipe.*

***Stack venting**: Extension of the vertical discharge pipe above the highest branch discharge pipe connection that terminates at an end, open to atmosphere.*

Ventilating stack *Main vertical ventilating pipe, connected to the discharge stack to limit pressure fluctuations within the discharge stack.*

Drain venting *Venting near the end of a main drain or branch drain, the vent being installed on the wet side of the last fixture.*

A combination of the above can be used on larger projects. These methods have limitations, as open vents require penetrations through the roof to allow the atmospheric air to balance the pressure transients within the sanitary drainage system, as well as the requirement for the pipe to carry this air. Recent research is proving that the current practice of using a 50% smaller vent pipe network is unsafe as this can lead to trap seal depletion. The only correct and safe way to use a passive pipe vent system is that all vent pipe work must be 100% larger DN100 stack = DN200 vent pipe network.

This is a paper from Prof John Swaffield who was the leading expert in drainage

1. Transient propagation.

The prevention of cross contamination via depleted trap seals has been a design consideration over the past 100 years. The invention of the water seal trap in the 18th Century - a 'U 'bend' immediately downstream of the appliance with a water depth of 50 - 75 mm - has remained the most effective barrier to sewer gasses. Traps respond to network pressure so system failure involving cross infection may follow the depletion of trap seals by air pressure transient propagation. Modern design, water conservation and the need to economise demands a re-evaluation of drainage design that recognises the unsteady nature of system flows and the effects of pressure transient propagation. Demands on urban living space that increase system loading due to occupation levels in excess of those envisaged at the design stage, will compromise drainage operation. Pressure transient propagation leading to system failure is associated with destructive forces in complex fluid systems. While the definition of failure is system dependent, the underlying principles of surge propagation, suppression and control remain constant. Transient propagation communicates flow demand - negative transients demand an increase in flow while positive transients reduce flow and increase pressure.

Figure 1 illustrates a single stack conveying appliance discharges as annular water flow, of 6-10 mm thick in stacks up to 150 mm diameter that reaches terminal velocity based on flowrate, stack diameter and roughness, within two floors and entrains air that enters via the open stack termination, generates a frictional pressure drop in the dry stack and pressure losses at discharging branch to stack junction airpath occlusion. Shear forces between the annular water and the air core, due to 'no-slip', generates an entrained airflow. If this airflow exceeds that appropriate to the shear force in any section of the stack the air pressure reduces as the air is drawn past the water film. At stack base the transition to free surface flow generates a water curtain, resulting in the generation of a 'back' or positive pressure. This overall mechanism depends on water flow and network parameters, increasing stack diameter decreases entrained airflow velocity; sweeping the stack base decreases back pressure; sweeping branch entry to the stack reduces airpath occlusion. Negative stack pressure draws trap seal into the system while positive pressure may lead to 'bubble through' from the system to habitable space.

This appreciation of system operation, developed in the UK at BRE and in the US at NBS, was empirical and exclusively steady state, Applications of fluid mechanics analysis in the 1950s, (Lillywhite and Wise 1969), was limited to steady state and remained so until the advent of computer based simulation. Appliance discharges are time dependent and random so the water downflow displays temporal and spatial unsteadiness. Flow conditions also depend on external pressure perturbations from the remainder of the building, the downstream sewer network and wind shear over roof level terminations. While the complex nature of these flow conditions was recognised, the lack of an accessible theoretical basis for design led to 'rule of thumb' practices that ignore the fact that the laws of physics transcend national frontiers.

Drainage systems display classic unsteady flow, variously described as pressure surge or waterhammer. Joukowsky (1900) investigating waterhammer in the St Petersburg Water Works, laid the foundations of *modern transient theory, identifying the importance of wave speed and the reflection and transmission of transients at system boundaries that applies to the air pressure transients propagated in building drainage systems due to sudden increases in annular water downflow or reductions in entrained airflow that travel throughout the system. Joukowsky's fundamental relationship*

$$\Delta p = -\rho c \Delta u \qquad (1)$$

indicates that an increase in airflow of 1 m/s would generate a -40 mm water gauge transient when air density and an acoustic velocity of 320m/s are system characteristics. Equation 1 introduces the first rule of surge protection – reduce the rate of change of the flow velocity.

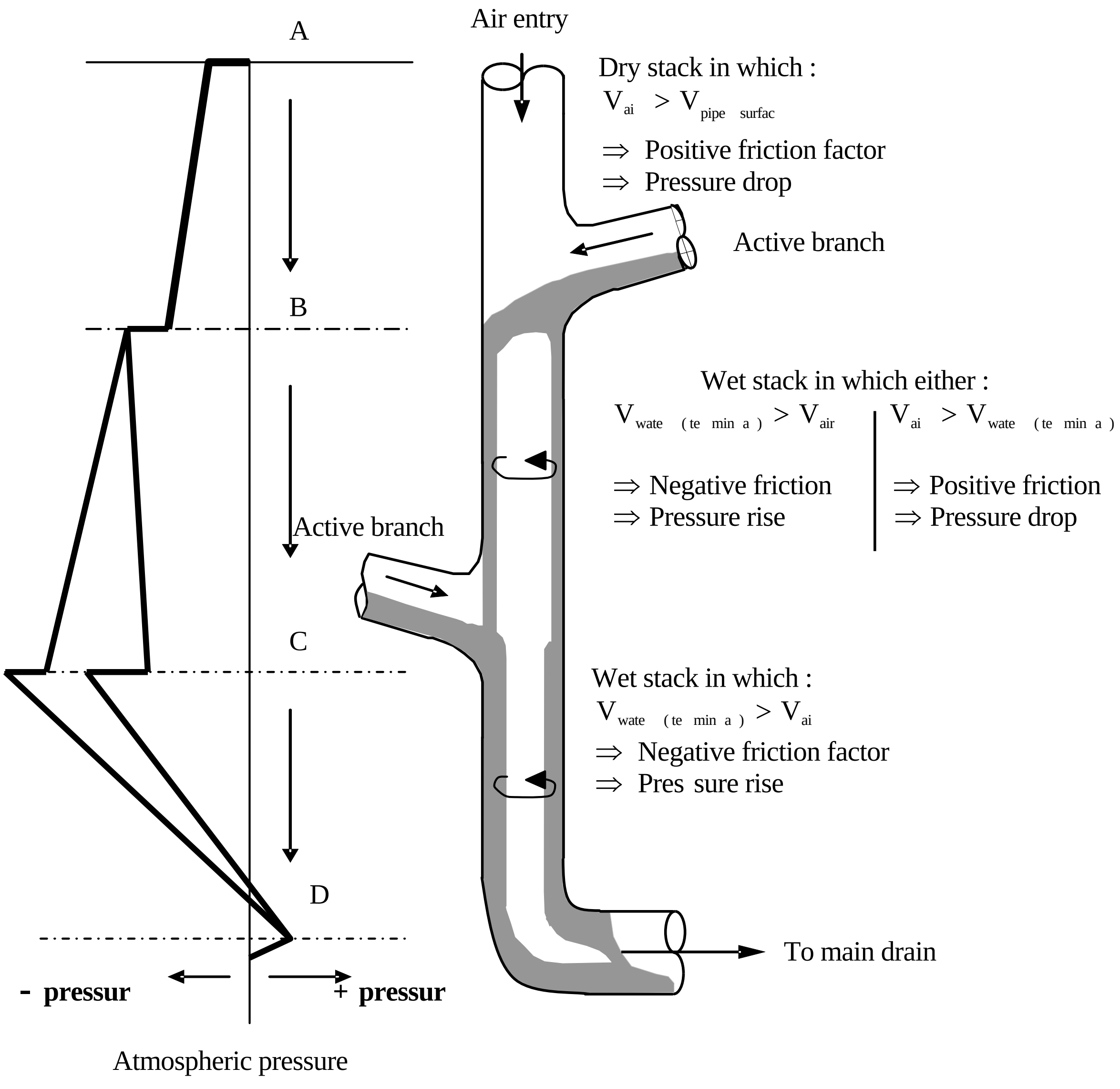


Figure 1 - Water and entrained airflows in a drainage vertical stack, illustrating the possible pressure regime established under steady flow conditions. Note concentrated losses at A, B and C and the 'back pressure' at D, the sewer entry.

Interruptions to the airpath may occur at the base of the stack, or at offsets, if a rapidly increasing annular water downflow causes local surcharging. A 'severe' positive transient could force air through the appliance trap seal – 'bubble through'- or displace the trap seal water upwards leaving the trap wholly or partially depleted. Where the positive pressure displaces the trap seal sufficiently to allow air *bubbles to pass through to the appliance, trap seal depletion may occur on cessation of the positive pressure as the trap seal water is allowed to flow into the trap. Once generated a transient will continue to propagate throughout the network displacing every trap seal it encounters until relieved. This introduces the second rule of surge protection – position the relief device between the source of the transient and the item to be protected.*

2. Mathematical basis for a vent system simulation.

Network air pressure transients depend on the rate of change of water flow and interrupted airflow. Air pressure transient propagation belongs to a family of unsteady flow conditions described by the St Venant equations of continuity and momentum solvable via the Method of Characteristics, introduced in the 1960s, (Lister 1960, Streeter and Wylie 1967). Jack (2000) introduced a 'pseudo-friction factor' model of the annular water to entrained air core interface that drives the simulation of combined discharge flows and air entrainment. This analysis includes the case of airflow entrained by high water flows in the lower levels of the wet stack exceeding that appropriate to the water flow in the upper levels. This allows the modelling of increasing pressure in the lower levels and decreasing pressure further up the stack as the air is drawn past the slower moving upper level water film that impedes its passage.

The St Venant equations link mean airflow velocity and wave speed as air pressure and density are interdependent. These quasi-linear hyperbolic partial differential equations are transformed via the Method of Characteristics into finite difference relationships, equations 2 to 5, linking conditions at a node one time step in the future to current conditions at adjacent upstream and downstream nodes, Figure 2.

For the C^+ characteristic :

$$u_P - u_R + \frac{2}{\gamma - 1}\left(c_P - c_R\right) + 4 f_R u_R |u_R| \frac{\Delta t}{2D} = 0 \quad (2)$$

when $$\frac{dx}{dt} = u + c \quad (3)$$

and the C^- characteristic :

$$u_P - u_S - \frac{2}{\gamma - 1}\left(c_P - c_S\right) + 4 f_S u_S |u_S| \frac{\Delta t}{2D} = 0 \quad (4)$$

when $$\frac{dx}{dt} = u - c \quad (5)$$

where the wave speed c is given by $c = (\gamma p/\rho)^{0.5}$ *(6)*
and local pressure is calculated as $p_{local} = [\,(p_{atm} / \rho_{atm})\ (\gamma/c^2_{local})^{\gamma}\,]^{1/(1-\gamma)}$ *(7)*

Time step and internodal distance are governed by the Courant Criterion, defined as $\Delta t<\Delta x/(u+c)$. In the dry stack f_R and f_S are determined from Colebrook White. In the wet stack they are functions of time, location and annular water downflow and drive the simulation by generating the entrained air flow, Jack (2000).

Only one characteristic exists at each boundary so an additional equation is required at each pipe termination, e.g. airflow vs. pressure for AAVs, constant pressure for open terminations, zero velocity at dead ends, a combination of these for PAPA™s, partial reflection and transmission coefficients at pipe junctions or the momentum equation describing trap seal motion. An unique feature is the pseudo friction factor that drives the entrained airflow condition, effectively a distributed boundary condition with variable friction factor values at each node. Boundary conditions may be active or passive - pressure relief by vent connection to atmosphere is a passive boundary while active boundaries include AAVs, where inflow depends on local pressure differentials, or variable containment volumes that open in response to local positive pressure.

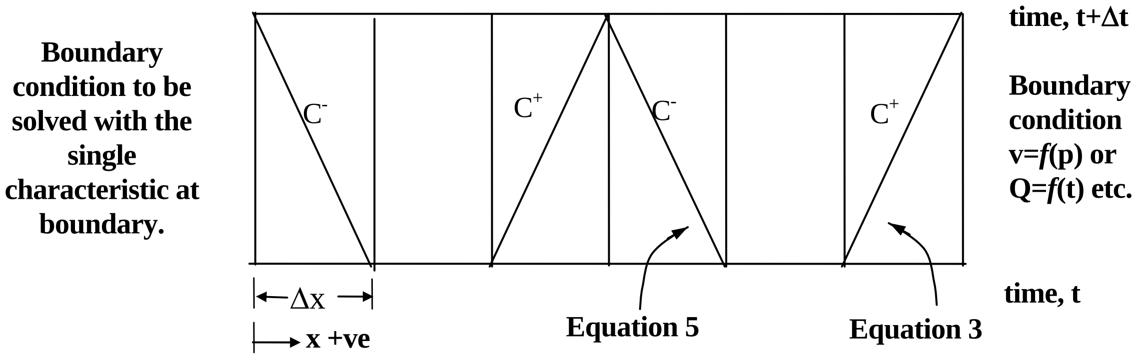


Figure 2 - St Venant equations of continuity and momentum allow airflow velocity and wave speed to be predicted on an x-t grid. Note $\Delta x<1.0$ m, $\Delta t < 0.003$s.

3. Air pressure transient control and suppression – traditional 'passive' venting.

While the propagation of low amplitude air pressure transients is a natural and unavoidable consequence of appliance discharge to a building drainage system, the protection of appliance trap seals is dependent on the control and suppression designed into the system. From the late 19th century, this control and suppression depended upon fixed venting running parallel to the wet stacks. The earliest 'two pipe' systems separated foul from general waste flows with each appliance independently vented. In the 1930s the 'one pipe' system discharged all appliances to a common wet stack but again separately vented appliances. In the 1970s the UK introduced a 'single stack' system that dispensed with separate vents although above 30 floors a parallel vents stack cross connected into the wet stack was introduced. All these designs featured vent stacks smaller in diameter than the wet stack and all represent 'passive' control and suppression as there is no interaction between the control mechanism, the fixed in place vent, and the transient. Two basic rules of surge suppression have been identified –

1. Transients may be attenuated by reducing the rate of change of flow velocity. This follows from equation 1 and implies that flow should be diverted in the case of a positive transient or, in the case of a negative transient added through an adjacent inlet.

2. The second basic rule is that the surge alleviation should be positioned between the source of the transient and the equipment to be protected.

While the fixed in place vent solution provide a degree of flow diversion or addition, criteria 1 above, its efficiency in this role is limited by fundamental misunderstandings of the operating mechanism of the vent stack currently embedded in the codes.

Fixed in place vents do not meet the second criteria in any way. The source of any relief to offset the pressure regime imposed on the system by the passage of the transient is the reflection of the transient at the upper open termination of the vent system. Thus the potentially trap seal depleting transient has already passed all the traps to be protected before any relieving reflection can be generated by the open termination.
The pressure transient transmission and reflection coefficients at junctions may be determined from the following expressions (Swaffield and Boldy 1993)

$$C_{Transmission} = \frac{2\frac{A_1}{c_1}}{\frac{A_1}{c_1}+\frac{A_2}{c_2}+\frac{A_3}{c_3}} = \frac{2}{1+\frac{A_2}{A_1}+\frac{A_3}{A_1}} = \frac{2}{1+\frac{A_{Branch}}{A_{Incoming}}+\frac{A_{Continuation}}{A_{Incoming}}} \quad (8)$$

$$C_{Reflection} = \frac{\frac{A_1}{c_1}-\frac{A_2}{c_2}-\frac{A_3}{c_3}}{\frac{A_1}{c_1}+\frac{A_2}{c_2}+\frac{A_3}{c_3}} = \frac{1-\frac{A_2}{A_1}-\frac{A_3}{A_1}}{1+\frac{A_2}{A_1}+\frac{A_3}{A_1}} = \frac{1-\frac{A_{Branch}}{A_{Incoming}}-\frac{A_{Continuation}}{A_{Incoming}}}{1+\frac{A_{Branch}}{A_{Incoming}}+\frac{A_{Continuation}}{A_{Incoming}}} \quad (9)$$

It will be seen from equations 8 and 9 that the wave speed in each pipe or duct is included in the coefficient determination, however in the case of low amplitude air pressure transient propagation in building drainage and vent systems the pipework may be taken as rigid and the wave speed in air as constant, simplifying the equations.

Similarly it will be seen that the transmission and reflection coefficients depend upon the identification of the pipe carrying the incoming transient. The junction will present different coefficients for transients arriving along the branch or the continuation pipe. Thus equations 8 and 9 have been re-cast in terms of the pipe carrying the incoming transient (pipe 1 in Figure 3), the branch (pipe 2 in Figure 3) and the continuation pipe (pipe 3 in Figure 3) as this will make calculation of the coefficients easier.

The transmission coefficient at a junction of three equal diameter pipes is 66% of the incoming wave, Figure 4. A -33% reflection of the incoming is also generated. If the branch vent, Pipe 2 in Figure 3, is reduced in diameter then the transmitted wave strength increases – e.g. if the vent is half wet stack diameter then the transmitted wave is increased to 90% of the incoming wave. This offers no reduction in the transient propagating up the wet stack. If the vent has a greater diameter than the wet stack then the vent system starts to have an influence on the transient propagated up the building, e.g. if the vent stack is double the wet stack diameter then the transmission reduces to 33%. Note that the diameter of the cross vent, Figure 3, is as important as the vent diameter in restricting wave attenuation.
All national plumbing suggest equal or smaller diameter vent stacks compared to the wet stack, hence there is a fundamental misunderstanding of the mechanism of surge protection embedded in the design codes.

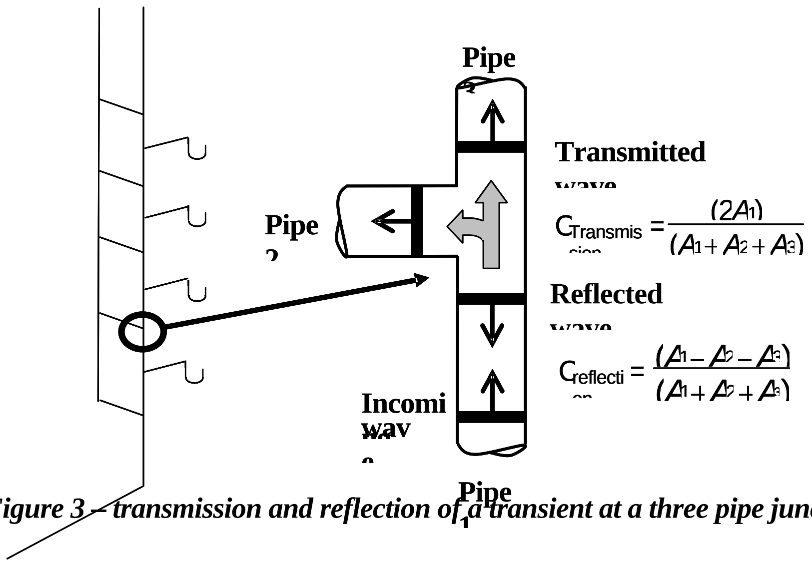


Figure 3 – transmission and reflection of a transient at a three pipe junction.

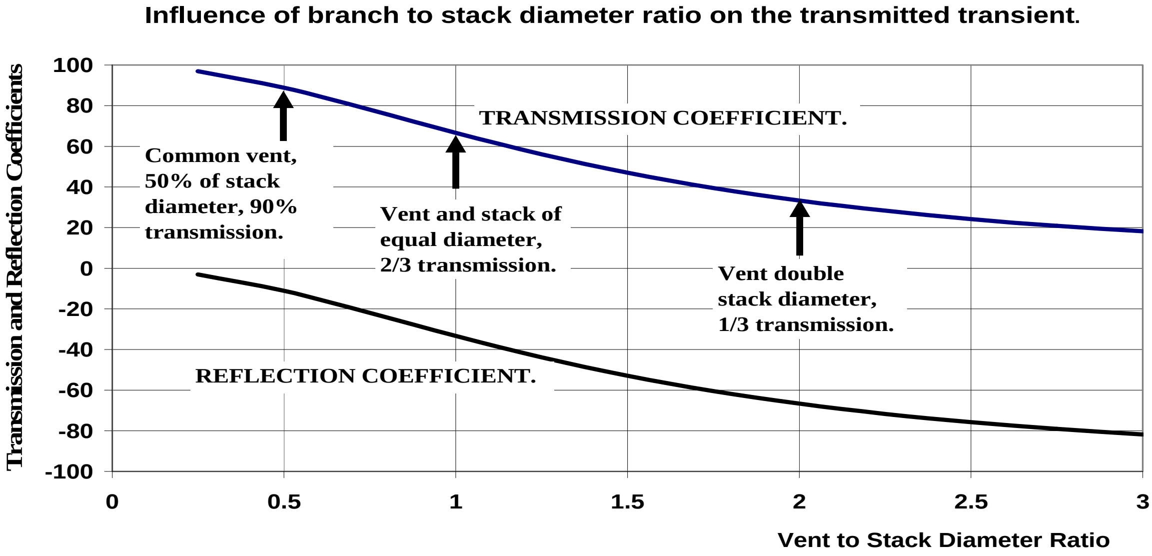
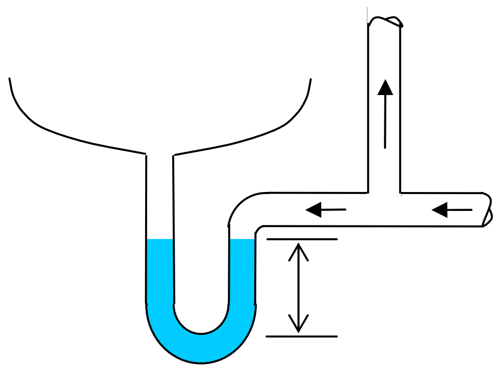


Figure 4 – The transmission and reflection coefficients at a three pipe junction depend upon the relative area ratios of the joining pipes. Figure 3 illustrates the necessary equations defining these coefficients.

It is the ratio of the pipe cross sectional areas that determines the coefficients rather than actual pipe diameters. If the traditional passive venting of individual traps back to the vent stack is considered, Figure 5, then it will be appreciated that a small diameter vent connected into the trap branch will have little effect.



Diversion of incoming transient depends on area ratio of the vent pipe cross sectional area to that of the trap branch.

To be effective in reducing pressure applied to the trap seal the vent should be greater in cross section than the branch.

Figure 5 – Passive vent connections applied locally to protect trap seals also require a larger vent diameter to be effective.

4. Air pressure transient control and suppression – active control.

The need to minimize external pipework and the advent of taller buildings led to the introduction of the single stack system in the 1970s. Further reductions from the mid 1980s introduced Air Admittance Valves installed within the habitable space to allow inwards air pressure relief. Active transient control extends this approach to include both positive and negative transient suppression to provide trap seal retention and prevent cross contamination of habitable space. Figure 6 illustrates an air admittance valve, AAV, and the positive air pressure attenuator, PAPA™ or flexible containment

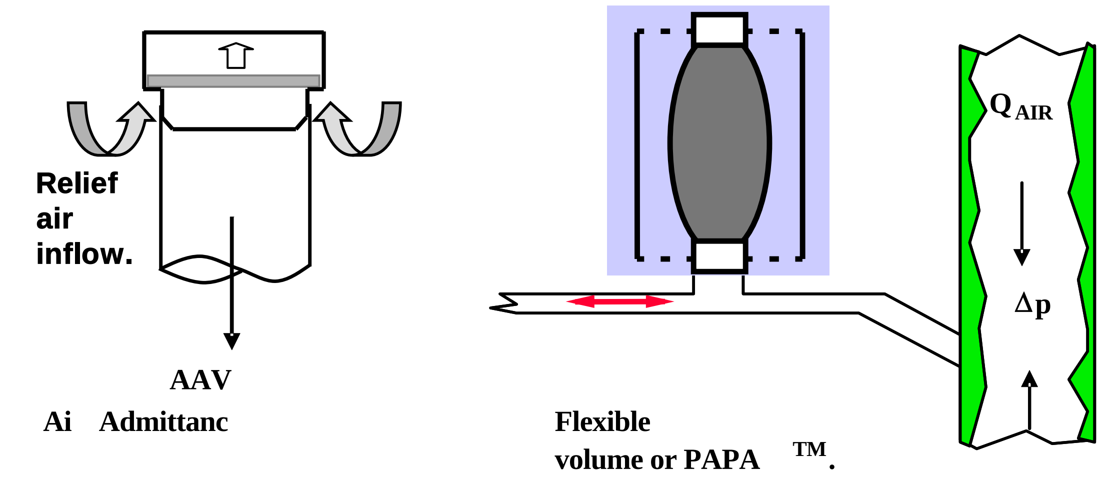


Figure 6 - Active air pressure transient suppression devices to control both positive and negative surges.

volume, capable of absorbing transients until pressurized. The principle of operation of. the AAV is to open whenever the local air pressure falls below a predetermined level in the local network allowing allowing an air inflow that does not require the transient to travel the whole height of the building to the first roof line open termination

The PAPA^{TM} allows entrained airflow to be diverted into the containment volume and reduces the rate of airflow deceleration by providing a diversion path. The pressure rise associated with the flow stoppage (Swaffield et al 2005) is therefore reduced. Thus it may be appreciated that Active control and suppression meets both the criteria.

5. Evaluation of Active and Passive control and suppression strategies for a simulated network.

Figure 7 illustrates a network that will allow the direct comparison of several design solutions - All stacks and branches 100 mm diameter, the trap is a 50 mm seal and the vent stack is initially 80 mm diameter. Interfloor height is 5 m. The applied water flow is a 2 litre/s flow with a 0.8 rise time from 1.0 seconds. This trial will impose a negative transient on the network and will test the ability of the Active control AAV installation compared to various Passive venting solutions with differing vent stack diameters. The base of the stack is surcharged from 3.5 to 4.0 seconds to impose a positive air pressure transient onto the network to test the ability of the Active control PAPA^{TM} installation compared to various Passive venting solutions with differing vent stack diameters.

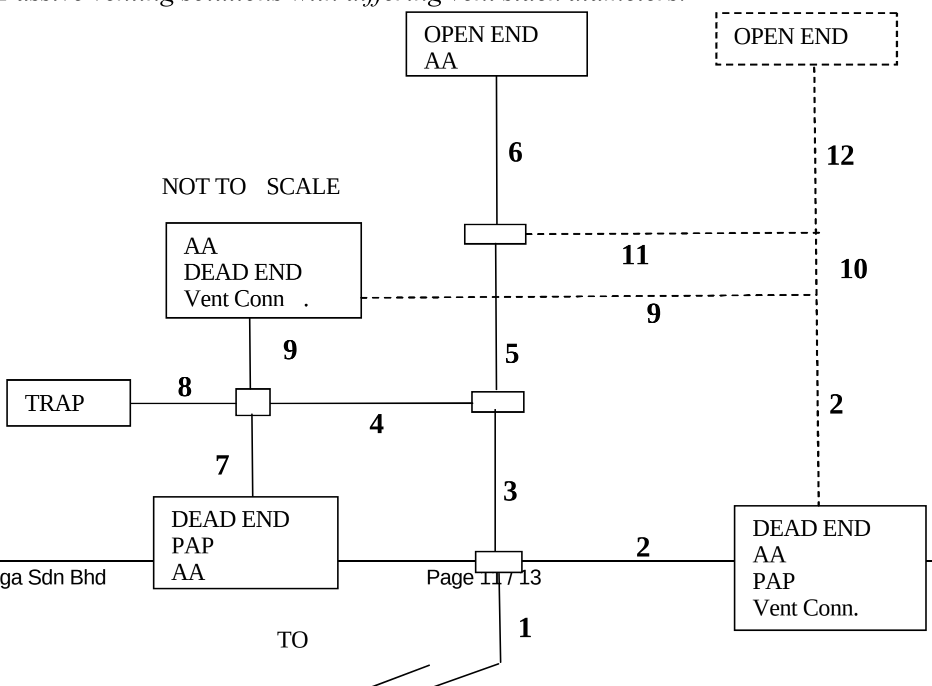


Figure 7 – a drainage and vent system to allow the evaluation of the relative performance of an Active or Passive transient control and suppression strategy.

Thus this single simulation includes both the possibility of induced siphonage and trap seal loss following a system surcharge dependent on system characteristics. Figure 8 illustrates the system operational conditions for two design cases, namely an Active Control application including distributed AAVs and a PAPA™ at pipe 2 and a traditional scheme using an 80 mm diameter parallel vent. Trap seal water is lost as the imposition of the annular water downflow generates negative stack air pressure. Seal loss is dependent on the waterflow acceleration – 2.5 litre/s^2 is a challenging criteria. Stack base surcharge results in a positive transient propagation, however the inclusion of the PAPA™ Active Control device prevents any additional trap seal loss. The parallel vent system does not control the positive transient and a secondary trap seal loss is experienced. Air pressure values in pipe 3 indicate that Active Control was more efficient at reducing the propagated positive transient following stack base surcharge

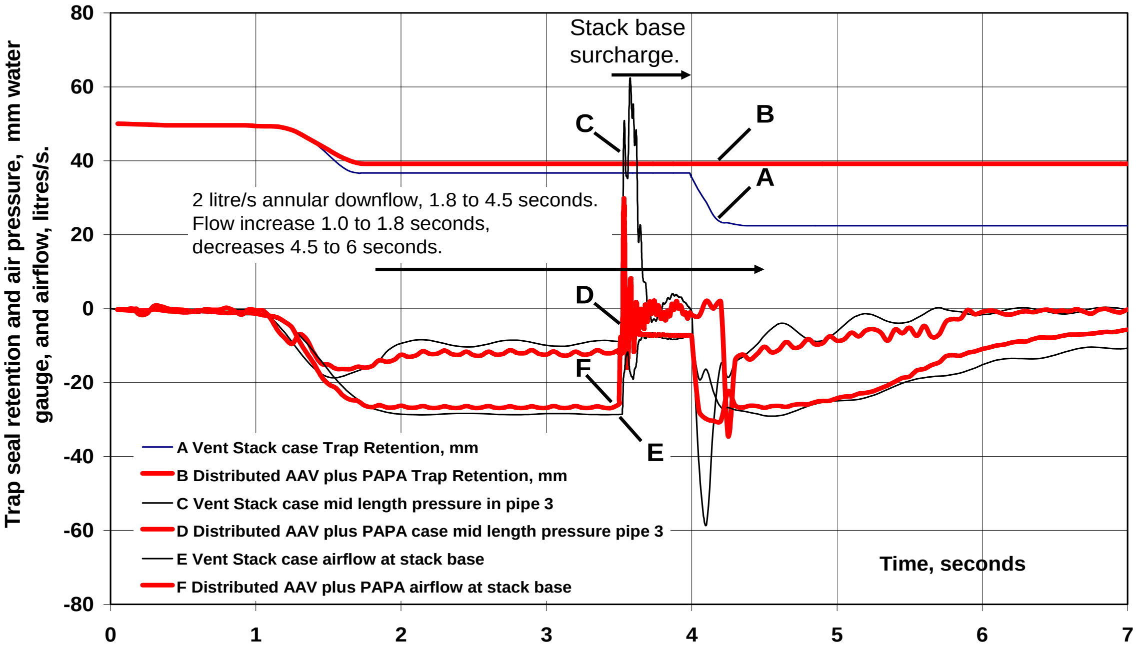


Figure 8 - Active Control through AAV and PAPA™ units compared to a standard parallel vent system.

Table 1 compares trap seal retention and peak pressure following surcharge for all cases. Active Control results in improved trap seal retention. Introducing AAVs alone reduces the positive transients experienced as the airflow into the network is reduced and so the stack base surcharge acts on a lower entrained airflow, generating a weaker transient. Table 1 indicates that for a parallel vent system to have a similar performance, the vent diameter would have to be twice that of the wet stack diameter at 200 mm, a result justified by the transient transmission relationship for junctions.

Reducing vent diameter increases the transmission coefficient and reduces attenuation. A 200 mm vent stack diameter reduces the transmission coefficient to 0.33 and allows greater diversion of the airflow that would have been brought to rest by the surcharge, thus conforming to the concept of surge protection already discussed – a similar but less efficient mechanism to that used by the PAPA™ (Swaffield et al 2005).

Network description, Figure 4	Trap seal retentior	Trap seal retention	Maximum pressure
	mm water gauge.	mm water gauge.	mm water gauge.
	at 3.5 seconds.	at 7.0 seconds.	mid length pipe 3
Parallel Vent Stack, 200 mm dia. with 100 mm dia. cross vents.	45.68	41.25	16.85
Single Stack, Distributed AAV pipes 6, 7, 9, 3, PAPA pipe 2.	39.20	39.20	28.16
Parallel Vent Stack, 200 mm dia. with 50 mm dia. cross vents.	41.82	36.38	22.18
Single Stack, AAV pipe 7 and 9, PAPA pipe 2.	35.08	35.08	18.90
Single Stack, AAV pipe 7 and 9, PAPA pipes 2 and 7.	34.48	34.34	18.39
Single Stack, AAV pipe 9, PAPA pipe 2.	33.49	31.12	20.90
Single Stack, AAV pipe 9, PAPA pipe 2 and 7.	33.54	30.67	18.13
Single Stack, Distributed AAV pipes 6, 7, 9, 2.	39.74	26.74	51.70
Parallel Vent Stack, 80 mm dia. with 50 mm dia. cross vents.	36.70	22.44	62.40
Single Stack, AAV pipe 7 and 9 no PAPA.	35.08	17.44	48.41
Single Stack, PAPA on pipe 2.	28.07	13.32	20.83
Single Stack, AAV on pipe 9.	34.00	12.82	55.94
Single stack, no AAV, PAPA or paralel vent.	27.80	1.58	62.43

Table 1 - Comparative system performance for various levels of Active Control and parallel vent sizing.

The modelling capability provided by the Method of Characteristics and the application of pressure surge analysis to building drainage and vent systems presents an opportunity to re-evaluate drainage design to reduce both complexity and labour and equipment costs while providing effective protection against cross contamination via the depletion of trap seals.

6. Conclusions.

Building drainage and vent system design relies on codes that in the main have been developed from practice 'rules of thumb' or steady state experimental research, much now dated or, as demonstrated by this paper, based on a fundamental misunderstanding of the mechanisms of transient control and suppression based on passive, fixed in place, vent networks – the traditional basis of system venting. There is a need to re-evaluate the design of these networks against current criteria, including water conservation, an escalation in building complexity, increased occupation levels, enhanced concerns as to cross contamination and ever increasing building height. Reliance on codes is no longer sufficient. There is a need to move drainage design into the same arena as other building services system design where validated simulation techniques provide a background to allow designers and consultants to deal with applications that lie outside the specific range of cases dealt with in codes. The Method of Characteristics driven simulations presented in this paper, along with the Active Control design opportunities, provide a basis for this re-evaluation that rests on extensive research as well as drawing on over a century of analysis and practice in the area of pressure surge theory. It is hoped that this paper will encourage the drainage design community to undertake this re-evaluation.

Studor- The above paper proves that if a pipe solution is used as proposed by KTA then the venting pipe (relief vent) must be upsized to 100% larger than the waste stack. In the PT towers this means that the relief vents must be re worked so that on the waste stack that are 150DN the relief vent pipes must be 300DN and on the waste pipes that are 225DN the relief vents must be 450DN. If the system is going to be rectified using a pipe solution. It can be seen by the above paper the Studor solution can be installed with minimal re working of the system without the need to re work the existing vent pipe network. A cross venting solution will only have no effect on the system unless the relief vents are upsized.

3.3 Stack Capacities

Flow enters the drain stack via a long-turn tee-wye or a sanitary tee. Depending on the rate of flow down from higher levels, stack diameter, pipe gradient and the type of stack fitting used, the discharge from the sanitary appliances may sometimes fill the entire cross sectional area of the stack as shown below due to the hydraulic jump phenomena:

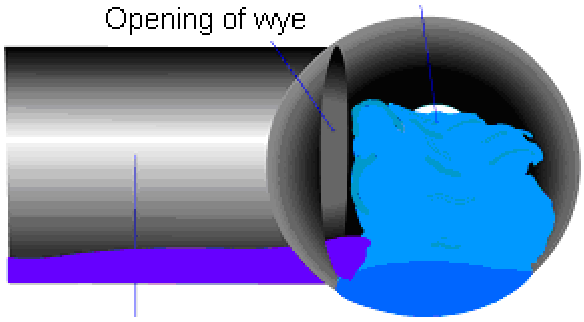


Figure 1.0 - Cross sectional view of a building drain branch during 'Hydraulic Jump" phenomena (More than ¼ full)

Dawson and Hunter, in their entirely independent investigations, found that slugs of water and the resultant violent pressure fluctuations did not occur until the stack flowed one-quarter to one-third full. The maximum permissible flow rates in the stack can be expressed by the formula:

$q = 27.8\ r^{5/3}\ d^{8/3}$

Where,

q = capacity (gpm)

r = ratio of cross-sectional area of the sheet of water to cross-sectional area of the stack

d = diameter of the stack

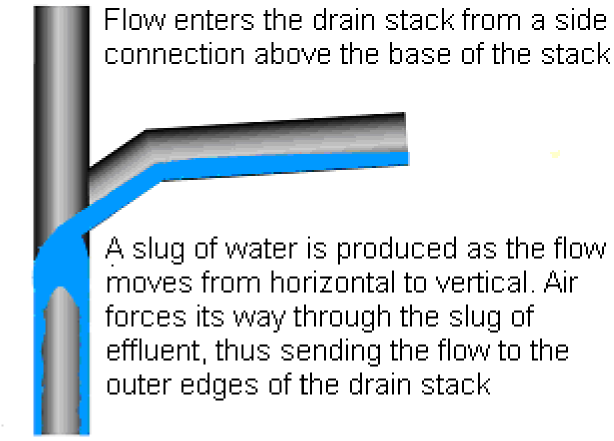
Values of flow rates when r = 6/24 (1/4), 7/24, 8/24 (1/3) are tabulated in Table 1.0.

Table 1.0 Maximum Capacities of Stacks			
Pipe Size (inches)	**Flow in GPM**		
	r = 1/4	**r = 7/24**	**r = 1/3**
2	18.5	23.5	---
3	54	70	85
4	112	145	180
5	205	270	324
6	330	435	530
8	710	920	1145
10	1300	1650	2055
12	2050	2650	3365

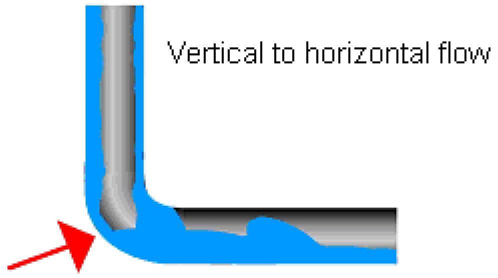
Most authorities have based their stack loading tables on a value of r = 6/24 (1/4) or 7/24.

3.4 Sanitary Design Theory

Sanitary Stack is a general term for a nominally vertical line of soil, waste or vent piping that collects soil and waste from fixture drains and horizontal branch drains. The soil or wastewater comes from water closets, urinals, sinks, basins and various other sanitary fixtures as shown below.



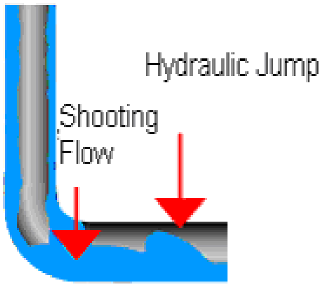
At the base of the vertical drain, flow enters the horizontal drain at a relatively high velocity. As flow enters a long sweep fitting at the base of the stack and is diverted from a vertical to horizontal direction, the water is subjected to centrifugal force and pressed against the lower curved surface in the fitting.



3.4.1 Hydraulic Jump

The centrifugal forces pressed against the lower curved surface in the fitting, results in what may be termed as 'shooting flow' or high velocity flow. A sheet of water with relatively uniform thickness is in contact with the lower curved surface in the base fitting and with the horizontal drain immediately downstream of the stack.

Hence, the velocity of the flow entering the horizontal drain is approximately four (4) times as much as the horizontal drain would maintain under uniform flow conditions.



The velocity of the water flowing in the horizontal drain slowly decreases with a corresponding increase in the depth of flow until a critical velocity is reached where the depth of flow suddenly increases.

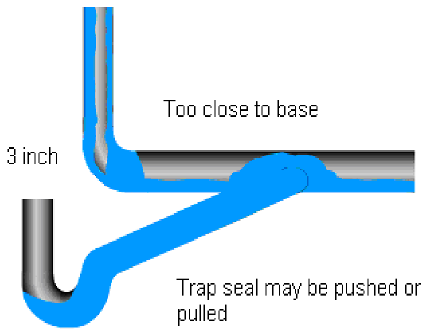
This increase in depth is often great enough to completely fill the cross sectional area of the pipe as shown in Figure 1.0. This phenomenon of sudden rise in depth is called the hydraulic jump.

The critical distance at which the hydraulic jump may occur varies. It is dependent upon the entrance velocity, depth of water that may already exist in the horizontal drain, roughness of the pipe, pipe diameter and pipe gradient.

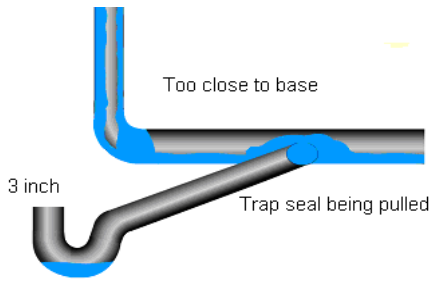
3.4.2 Hydraulic Jump And Its Effect To Water Seals

The increase in velocity at the base of the stack will have diverse effects on the trap seals of the horizontal drain connections if the horizontal connections are installed too close to the base, thus resulting in the trap seal either being pushed or pulled as shown below:

Trap seal before being pulled



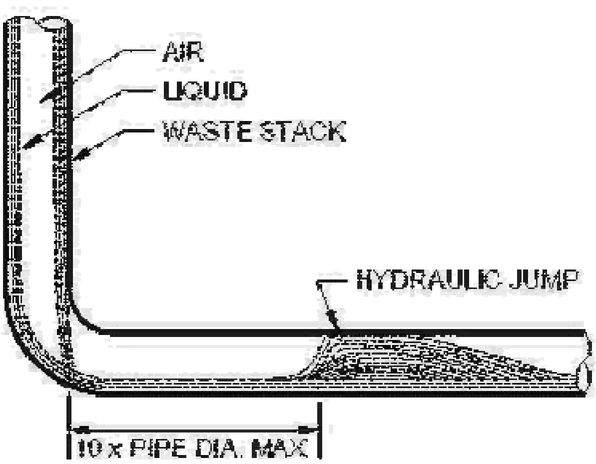
Trap seal after being pulled



Studor- accept some of KTA views on the Hydraulic jump, but in essence the transients are generated by a rate if change due to the closure of the airflow at the water curtain. From ASPE Chapter 50

1.1 Hydraulic Jump

2.4.1 As waste reaches the bottom of stack, it must change from vertical flow at the walls of the stack to horizontal flow along the bottom third of the area of the drain (assuming properly sized system). This change of direction is associated with a change in velocity. Gravity no longer has free access to the falling stream – it now acts on a fall of about ¼ inch per foot of travel. This transition takes place over a short length of pipe, depending on the stream velocity, the size of the pipe, roughness of the pipe surface, the solids content of the waste stream, temperature and a few other variables. At this transition a phenomenon called hydraulic jump occurs. As the stream slows the fast supply under runs the slowing run off, turbulence occurs and the pipe runs nearly full. This occurs within 10 pipe diameters from the vertical. See figure 2-1.



The reason there is a vent pipe network is that the velocity of changing the negative pressure into a positive pressure generates positive pressure. This pressure is known as a positive transient. It is a low amplitude, low volume pressure wave that is moving through the plumbing drainage system at 320 m/s (which is the speed of sound). It is commonly generated at the base of the stack when the water down flow breaks at the base of the stack, causing a water curtain. This is a temporary blockage and the negative pressure is reflected as a positive pressure. It must be noted that the wastewater down flow clings to the outside of the pipe and air travels in the middle of the pipe. The wastewater will cling to the walls of the pipe approximately 1 metre after leaving the branch pipe.

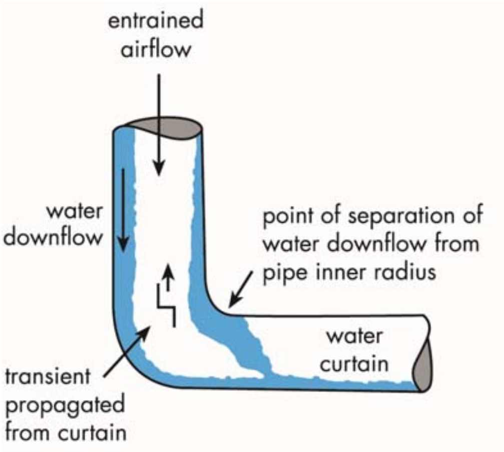


Figure 1: Generation of positive pressure transient due to curtain formation at base of stack

Figure 2: Two examples of full bore coverage

The water curtain (shown above) generates the main cause of the transients. It can be a full or partial closure that generates the transients.

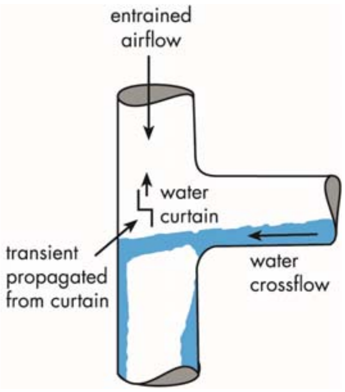
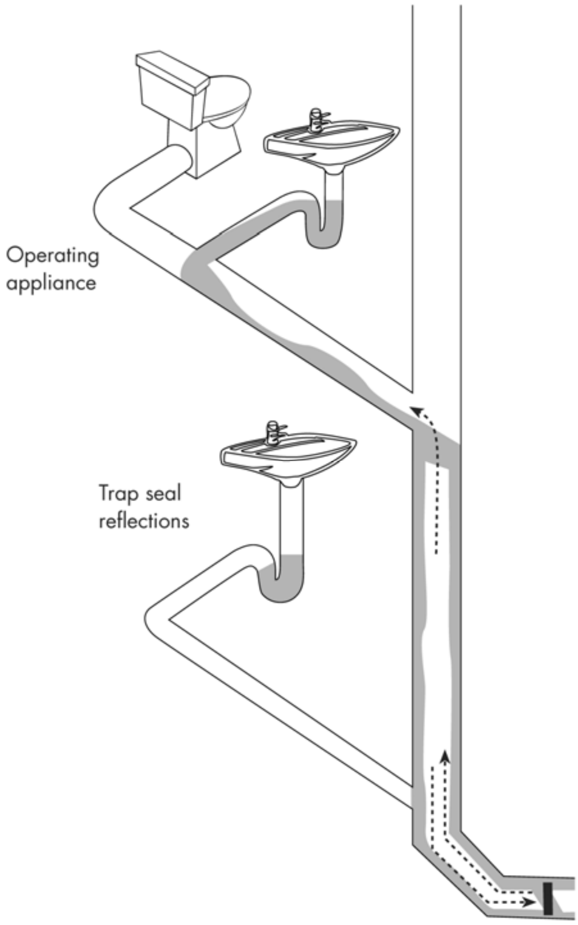


Figure 3: Generation of positive pressure transient due to curtain formation at inflow of branches

Positive pressure transients are not just generated at the base of the stack but also at points in the system such as offsets and partial closures at the connection of branches.



The positive transient is reflected at the closure, which is at the base of the stack. It is then reflected back up the system affecting the trap seals.

Figure 4: Reflection of the positive transient

To solve the transient pressure problem in a building plumbing drainage system using the conventional manner, a vent pipe network is added to the discharge pipes. This relieves the positive pressures.

It must be noted that although this system is commonly used and is an approved method, only recently data has been collected that prove faults in the existing venting system.

3.5 Current Problems Encountered In The Petronas Twin Towers

Insufficient venting is the main cause of the problem encountered in the Petronas Twin Towers which leads to the 'hydraulic jump' phenomena' that may either push or pull the trap water seals. Trap seals being pulled, causes the foul smell to escape through the trap water seals.

Studor agree with this although it is not the hydraulic jump but transients of reflected air that are causing the problem

When the hydraulic jump occurs and inadequate venting is provided, tremendous pneumatic pressures are built up in the area behind the jump. There have been cases where this excess pressure (greater than 1 inch column of water) has extended 12.2m (40 feet) up the stack, causing the water to 'gush out' from the sanitary appliances, especially in the water closets for the lower zone (9th floor to 15th floor) due to this 'hydraulic jump' phenomenon.

Studor agree with this although again it is the transients that are causing the problem not the Hydraulic Jump, the transients move in the system at 320m/s

4.0 DATA GATHERING PROCESS

From our data gathering process, the followings are the chronology of actions implemented by KLCCUH

NO.	DESCRIPTION	DATE	REMARKS
1	Inspection by Indah water - All manhole connections to Indah Water	June 2003	No blockages found

	were inspected - Main vent stack were inspected and rodded for possible vent restrictions		
2	Consultation with local (KTAT) and foreign design consultant (Flack + Kurtz)	July 2003	-
3	Installation of additional vent pipe at affected floors, clearing and extension of vent stacks	April 2004	Notified tenants to flush twice
4	Installation of additional vent pipe at level 8, Tower 2 (complete with in-line fan) to assist in venting (***lack of understanding the issues)***	January 2005	Completed and witnessed by consultant
5	Additional PVC vent pipe at level 6, Tower 2(***lack of understanding the issues)***	June 2008 – August 2008	-
6	Add vent pipe from urinal bowl to vent stack at affected floors (***lack of understanding the issues)***	January 2009	-
7	KLCCUH meeting with UK consultant who had experience in resolving back pressure issues for Taipei 101 in Taiwan (***This was Studor)***	November 2010	-
8	KLCCUH Indoor Air Quality (IAQ) measurement at level 9 to level 11, Tower 2 (***masking the problems solution)***	March 2011	IAQ is within acceptable limits

KLCCUH had been very helpful in providing to KTAT some As-Built drawings and technical write-up on this issue to assist KTAT in their investigation study.
(Refer to Appendix 1)

4.1 Site Investigations

KTAT conducted several site inspections with the assistance of KLCCUH to determine the cause of this hydraulic jump problem. Amongst the issues noted from the site inspections are:

1) 125mm diameter vent pipe connected to a 250mm diameter soil stack

Studor- as shown undersized and is a major issue to why the system is failing.

2) Additional piping connections to the existing sanitary stacks probably due to renovation works

Studor- This is showing that although extra venting has been used, due to the height of the building extra venting at the base of the building has not worked.

3) Foul smell from the lower zone Male toilets

Studor- the system has exceed 40mmWg

4) Slow discharge of water in the Male and Female water closets (WC) despite two (2) repeated flushing attempts.

Studor- The slow discharge and hence the need to flush the toilets twice is an issue that has not been discussed by KTA. Studor sight visit has observed that constant positive pressure is present in stacks. The slow discharge of the flush is due to the fact that this constant pressure is present. It is occurring when there are discharges elsewhere in the other stacks and the negative pressure and the air that flows it is entering the below ground sewer system and instead of traveling out of the building sewer system it is traveling back up the other stacks due to their size, active venting will reduce this effect. Using Active ventilation the amount of air moved will be reduced so this constant positive pressure will be eliminated

5) Movement of water column in the water closets seal traps especially in the lower zone of the Male Toilet areas

Studor – it is know that the lower part of the buildings are affected by negative and positive transients, this is due to the height of the building and the transient pressure communication time. In these towers it is over 3 seconds before the system can respond. Given that a discharge is

measured at 2 seconds this system will always be subjected to problems unless there are devices such as AAVs located at the point of need in the system.

6) Insufficient distance between the piping connections from the base of the sanitary stack and water seals

7) Presence of water droplets at the vent pipes

Refer to Appendix 1 for the photographs taken during KTAT's site visits.

5.0 PROPOSAL AND RECOMMENDATIONS

Based on the above findings and site investigations, our recommendations are to complete the remedial works in two (2) stages as follows:

Stage 1

1) To have cross venting at every floor to provide adequate stack venting system as recommended by BS EN 12056-2: 2000 as described below:

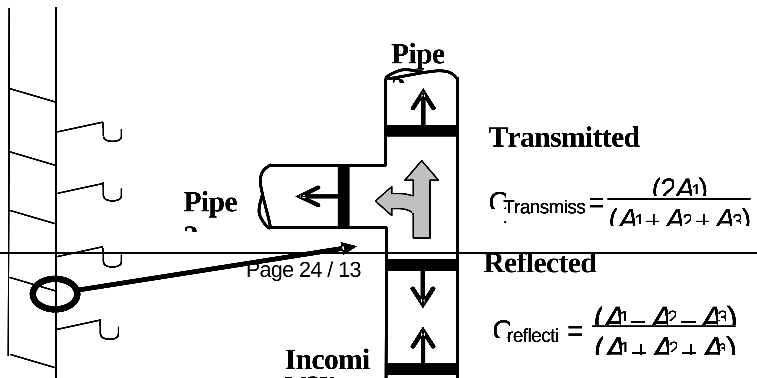
ND.3.6.2.1 Connections

In secondary ventilated stack systems (see Figure ND.5), the ventilating stack can be joined to the discharge stack by cross-connections, usually on each floor. These cross-connections should slope upwards from the discharge stack (67½° maximum) to prevent discharge water from entering the vent system and should be of the same diameter as the ventilating stack.

The lowest end of the ventilating stack should normally be connected to the discharge stack at or below the lowest branch connection; the upper end should preferably be connected to the stack vent or pass through the roof to the atmosphere.

Extracted from BS EN 12056-2: 2000

Studor- this is from the informative section of the BS EN 12056-2 and is taken from the BS5575 the old British standard. It must be noted that in the UK the BRE test rig was only 5 floors and that the principles of the BS 12056-2 is for a 20 story building.



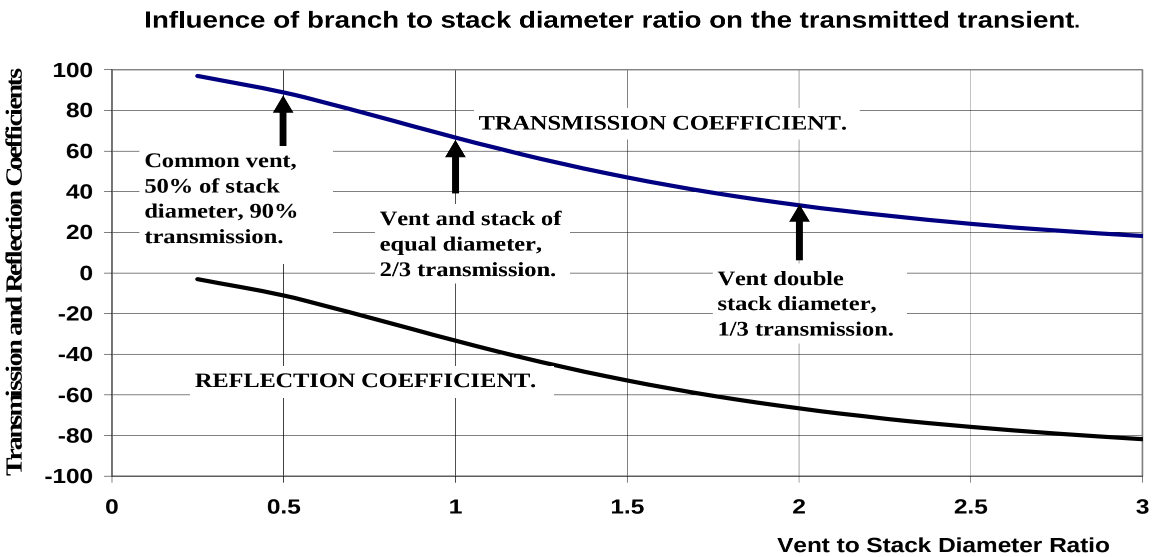
Note that the diameter of the cross vent, Figure 3, is as important as the vent diameter in restricting wave attenuation.
All national plumbing suggest equal or smaller diameter vent stacks compared to the wet stack, hence there is a fundamental misunderstanding of the mechanism of surge protection embedded in the design codes.

Based on ASPE Data Book – Volume 2 (Refer to Table 3-5), the **maximum venting distance** for a 125mm diameter vent pipe connected to a 250mm diameter soil stack is only 22.9m (75 feet), which is insufficient to vent the soil stack.

The recommended vent pipe size based on this guideline should be 200mm in diameter to meet the height of 1,000 feet (304.8m).

Studor- From the current research which ASPE has not yet adopted, we can see that the vent system needs to be larger in vents sizing than waste pipes if it is going to divert the transient away from the water trap seals. Using the reflection coefficient table below it can be seen that the pipe size should greater than the waste stack if the pipe method is used. Studor solution will require no need to up size any of the vents in the building.

Figure 3 – transmission and reflection of a transient at a three pipe junction.



Therefore, cross venting is proposed at each level to ensure adequate stack venting as recommended by BS EN 12056-2: 2000.

Studor- Disagree that this will have any effect on the current issues unless the cross vents on each floor and the relief vents are upsized to 100% than the waste pipes. Studor stress that BS EN 12056-2 is not designed for tall buildings such as the towers so that a recommendation that cross venting will solve the problem is unsafe verses current peer reviewed research.

Table 3-5 Size and Length of Vents

Size of Soil or Waste Stack, in. (mm)	Fixture Units Con-nected	Diameter of Vent Required, in. (mm)								
		1¼ (32)	1½ (38)	2 (51)	2½ (63)	3 (76)	4 (101)	5 (127)	6 (152)	8 (203)
		Maximum Length of Vent, ft (m)								
1½ (38)	8	50 (15.2)	150 (45.7)							
2 (51)	12	30 (9.1)	75 (22.8)	200 (61)						
2 (51)	20	26 (7.9)	50 (15.2)	150 (45.7)						
2½ (63)	42		30 (9.1)	100 (30.5)	300 (91.4)					
3 (76)	10		30 (9.1)	100 (30.5)	100 (30.5)	600 (182.9)				
3 (76)	30			60 (18.3)	200 (61)	500 (152.4)				
3 (76)	60			50 (15.2)	80 (27.8)	400 (122)				
4 (101)	100			35 (10.7)	100 (30.5)	260 (79.2)	1000 (304.8)			
4 (101)	200			30 (9.1)	90 (27.4)	250 (76.2)	900 (274.3)			
4 (101)	500			20 (6.1)	70 (21.3)	180 (54.9)	700 (213.4)			
5 (127)	200				35 (10.7)	80 (27.8)	350 (106.7)	1000 (304.8)		
5 (127)	500				30 (9.1)	70 (21.3)	300 (91.4)	900 (274.3)		
5 (127)	1100				20 (6.1)	50 (15.2)	200 (61)	700 (213.4)		
6 (152)	350				25 (7.6)	50 (15.2)	200 (61)	400 (122)	1300 (396.6)	
6 (152)	620				15 (4.6)	30 (9.1)	125 (38)	300 (91.4)	1100 (335.3)	
6 (152)	960					24 (7.3)	100 (30.5)	250 (76.2)	1000 (304.8)	
6 (152)	1900					20 (6.1)	70 (21.3)	200 (61)	700 (213.0)	
8 (203)	600						50 (15.2)	150 (43.7)	500 (152.4)	1300 (396.6)
8 (203)	1400						40 (12.2)	100 (30.5)	400 (122)	1200 (365.8)
8 (203)	2200						30 (9.1)	80 (27.8)	350 (106.7)	1100 (335.3)
8 (203)	3600						25 (7.6)	60 (18.3)	250 (76.2)	800 (243.8)
10 (254)	1000							75 (22.9)	125 (38)	1000 (304.8)
10 (254)	2500							50 (15.2)	100 (30.5)	500 (152.4)
10 (254)	3800							30 (9.1)	80 (27.8)	350 (106.7)
10 (254)	5600							25 (7.6)	60 (18.3)	250 (76.2)

Extracted from ASPE Data Book – Volume 2

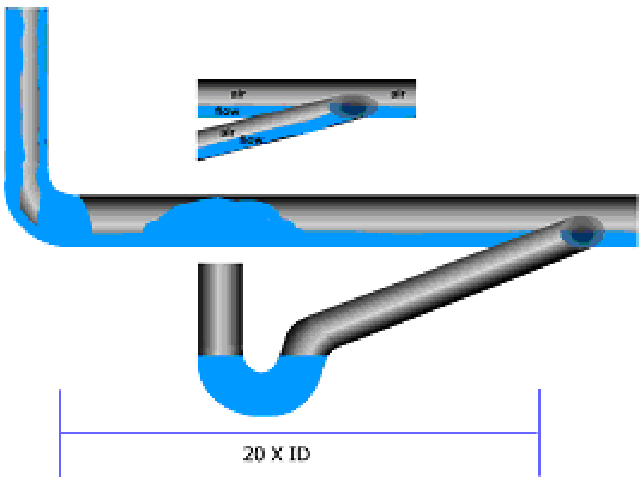
2) To propose air admittance valve at every 20m-height intervals calculated upwards from the 7th floor for the existing 125mm diameter vent pipe.

Studor- does not fully understand this recommendation it has no technical basis apart from understanding in part that a point of need of air ingress using AAVs may be of benefit. As a leading supply of AAVs in the world Studor would recommend a fully active solution taking into account negative and positive pressure solution.

3) To dismantle the in-line fan at the vent pipe at level 8, Tower 2 in order to have a free flow of air to balance the atmospheric air pressure in the vent piping system

Studor agree with this view, and do not understand why in the first place that a fan used to generate a negative pressure would be placed on the system. In our opinion this has made the situation worse and shows a fundamental lack of understanding of the system operation.

4) Maintain a 20-pipe diameter downstream from the base of the stack for the building drain branch connection as shown below.



5) Rod the horizontal run of the discharge stacks to ensure it's free of any blockages for the lower zone at the Male and female toilets from the 9th floor to the 15th floor.

Stage 1 is proposed to increase the effectiveness of the venting system and to mitigate the problems encountered.

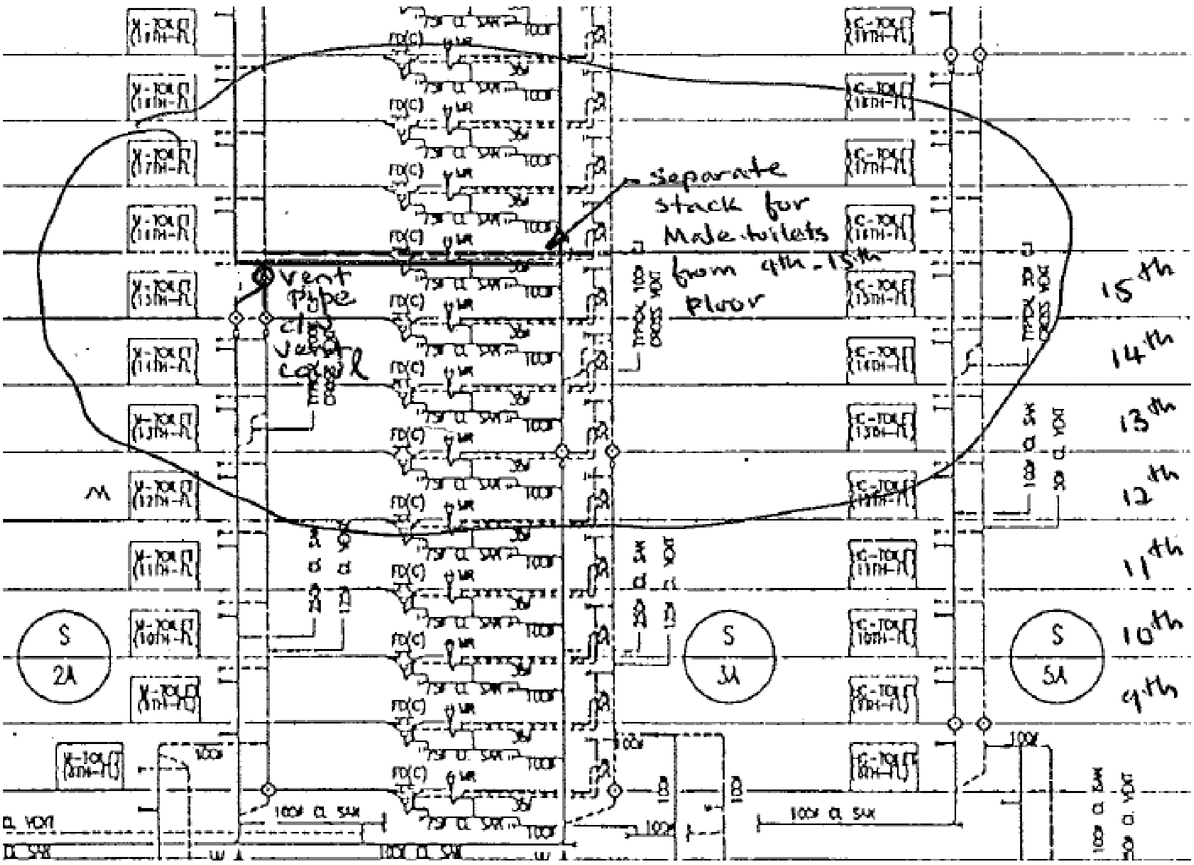
Studor- Only if the upsizing of the vent system is 100% larger than the waste stack. We also believe there is no space to do this in the building and to do this would require the entire stacks to be taken off line preventing the use of bathroom facilities in the building for a number of months per a stack, as well as the health and safety issues of having the system open within a operating building. The Dyteqta/ Studor solution would have no requirement to take the bathrooms off line in working hours as the system will be rectified over time out of hours.

<u>Stage 2</u>

1) Have a separate sanitary stack system for the lower zone from 9th floor up to 15th floor at the Male toilet by diverting the existing S2 stack connection located at high level of the 15th floor to the S3 stack that is currently being utilized for mop-receptor.

Studor-This approach is intended to take the lower floors that currently have issues and to tie them in at a higher level on the 15th floor. This is a reactionary idea as the fundamental misunderstanding of the problems that are occurring in the building, please note that the transient speed is 320 m/s , so the positive transient will start to affect the 16th floor and above if this solution is adopted. The pressure regime in the building needs to be addressed. Please note the comment below comes from the informative section of the BS version of the EN standard and is based on the old British standard, which again is based on BRE 5 floor test rig and this intern is based on a steady state results.

This conforms to BS EN 12056-2:2000 guidelines which states that 'for larger multi-story systems, it is better to connect the ground floor appliances to their own stack or the horizontal drain and not directly to the main stack. For buildings over 20 storeys high, it may be necessary to connect both the ground and first floor appliances in the same manner'.



Proposed Vent and Soil Stack off-set to be provided at high level of 15th Floor

Studor- The solution provided by KTA is not incorrect to with the current experience and information that they have in regards to the standards and data books available. The issue is that the understanding that KTA have that the hydraulic jump phenomenon is causing the problems is only part of the issues the towers are experiencing. It is also fair to say that the original design of the building was not incorrect given the data that was available back in 1994. But for the last 10 years extensive PhD research has found that these design principles are incorrect and this can be seen by the problem that the towers are facing. Studor and Dyteqta have on the basis of the current research developed solutions to deal with the problems that the towers are facing and with the high level

of understanding and the tools for forensic monitoring can fully provide recommendations and products that will solve the towers issues quickly and without the requirement of removing and upsizing of the vent system and there will be no requirement to withdraw bathrooms from use will the rectification work takes place. The Dyteqta monitoring will be used to ensure that any remedy has worked as it provides full time monitoring of the water traps in the building.