What dreadful noise of water in mine ears!*

Plumbing Noise – A Phenomenon of Urban Living

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The buildings we occupy, our homes and places of work or recreation, are a haphazard mixture of machine precision and of handcrafts that were built far better by ancient Greeks and Romans. We expect high quality in many aspects of buildings, but we may settle for the primitive when we consider such basic requirements as plumbing systems – on the one hand, the delivery of water fit for drinking and bathing, and on the other, the disposal of waste. One of the more primitive aspects that still persists, despite plentiful information on how it can be avoided, is noise from plumbing systems. It is difficult to understand why this situation should even exist throughout our technically advanced society when it can be easily controlled and is not tolerated in many other western countries. Meanwhile, as the debate over better controls continues, it is hoped that a review of several examples typical of north American building since World War II will demonstrate that a great deal can easily be done to avoid or correct plumbing noise.

Historical records confirm that some ancient societies had developed fairly sophisticated methods for water supply and disposal of waste, but these skills had been largely forgotten when the societies declined or, like the Roman empire, were over-run by barbarians. For much of the 1,000 years following the decline of Roman influence in Europe, societies reverted to little more than basic survival, with the loss of much previously acquired knowledge during the era generally known as the Dark Ages. Little attention was paid by contemporary writers to such details as disposal of everyday waste, although it was occasionally noted as being a serious concern because of the prevailing stench. One chronicler reported that approaching travelers were keenly aware of a town or village well before the buildings came into view.

This general state of affairs continued up until the mid-19th century, when the rapid growth of cities accompanied the Industrial Revolution. As perhaps the extreme example, the unprecedented expansion of the city of London around 1840 to a population of several million brought with it entirely new problems, including the need for housing and circulation and for an answer to the overwhelming presence of waste. While urban administration and maintenance of records on city dwellers were fairly sophisticated, fundamental concepts of health had changed little since ancient times, and no connection was made between the filthy living conditions and the outbreaks of disease that occurred periodically.

In the wake of several epidemics of cholera in the 1840s, a social planner for the city of London recognized the need to get rid of waste by building sewers. However, his plan included dumping the waste directly into the River Thames, which was also an important source of drinking water, resulting in a substantial increase in cholera deaths. It remained for a brilliant doctor to recognize the transmission of disease from waste to drinking water, but it took him another 20 years to demonstrate convincingly from the municipal records that the death rate was highest where drinking water was taken from the same location as sewage was dumped into the river.[2]

Subsequent action to avoid this cycle of disease demonstrated that high concentrations of people could exist in cities with relative safety, provided that good sanitary practices were followed. This doctor's insight led to the generally accepted concepts of protecting water supplies and disposal of waste that form the basis of today's plumbing systems. While we usually take for granted the reliability of such services, we are occasionally reminded that they can be quickly destroyed by disasters such as created recently by hurricane Katrina and the widespread destruction in Baghdad. So perhaps hearing the noise of plumbing systems should actually be a cause for celebration rather than for complaint.

Development of Noise Standards

By the mid-twentieth century, the development of buildings using light-weight, high-strength materials, together with corresponding advances in building systems design, had made closely spaced and very tall buildings acceptable for living and working. However, this combination, in conjunction with the contrast from the quiet surroundings that many occupants had enjoyed in rural and less-concentrated communities, created a conflict between the desire of the occupants for quiet and the noise and vibration generated by the various building systems they depended on for a healthy environment. The decades following World War II, for example, witnessed a substantial amount of investigation into improved privacy and methods of controlling noise and vibration from air conditioning systems, but little emphasis in the U.S. was directed toward plumbing noise.

In a paper presented to the Acoustical Society of America in 1964, a builder and developer in New York City, calling for acoustical isolation comparable to that noted in European housing, commented that " . . . the minimum standards of sound control for their lowest level of public housing far surpassed the best that we do for our most expensive apartments and homes . . ." and that their "plumbing stacks are completely isolated."[3] It would be reassuring to report that his admonition was heeded and that things have improved, but anyone involved with construction for the past 40 years, and particularly with residential design, knows that the reverse is more often true.

Since mid-century, by contrast, the development of socially oriented building standards in many other countries has led to more stringent regulations, including precise rules for how much noise may be generated by fixtures and how they should be installed to avoid disturbing neighbors. Emulating these standards by the U.S. is urged by various authorities but, to judge from the vociferous opposition from parts of the building industry in response to a national standard whose goal is simply to ensure an acceptable listening environment in elementary classrooms, it seems unlikely that any formal procedure for control of plumbing noise will be adopted in the foreseeable future.[4]

A review of the current edition of the California Building Code yields the following – Penetrations or openings in construction assemblies for piping . . . or ducts shall be sealed, lined, insulated or otherwise treated to maintain the required ratings.[5] This is exactly the same wording that was found in the Uniform Building Code in April 1981, which gives probably a fair indication of the glacial pace of progress.

Plumbing Noise Control Alternatives

Good planning of occupied spaces and grouping of services creates economies and, if done with care, allows for relatively easy isolation of noisier elements such as elevators, mechanical rooms and plumbing stacks from acoustically sensitive areas. However, as the scale of a building increases, the need for close attention to separation between occupants and noise of building services becomes more acute, so techniques for noise and vibration control must be included in the design from its conception.

Since the term plumbing noise could encompass many areas of study, the scope for the purpose of this discussion must be defined more closely. In this context it refers only to flow noise in domestic water systems, how it can become a source of distraction and

*From William Shakespeare, "The Tragedy of King Richard the Third."[1]

Based on a paper presented at Noise-Con 2007, Institute of Noise Control Engineering, Reno, NV, 2007.

annoyance, and how it can be avoided. It is well understood that noise due to turbulence in piping and valves is largely determined by the rate of flow. Rates of up to 2.3 m/s are generally considered to be satisfactory and reasonably quiet, but this also depends on the fixture. As a way of reducing piping costs, for example, flow rates above 2.5 m/s, often in conjunction with low-cost and inherently noisy fixtures, may be encountered in speculative apartment construction.

Noise due to turbulent flow travels along the piping to even distant locations where, through rigid connections to large radiating surfaces such as walls and ceilings, it will be amplified and radiated to the occupants. Simply avoiding rigid contact with the building structure – so that the wall or ceiling surface becomes a barrier to rather than a radiator of noise – can often provide adequate control of flow noise. However, it may not be sufficient for isolation from the vibration caused by mechanical sources such as kitchen waste disposers, washing machines or whirlpool bathtubs.

A recommended standard for plumbing noise levels in various settings is now included in the 2007 Handbook from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).[6] This is an important first step, but it will be quite some time before the preventive measures that these entail can be agreed upon. In any case, specification of quiet fixtures is hardly an answer in an era when the final step in design reviews has become the "value engineering" phase, where practically everything of merit is hacked from the design in an attempt to comply with an arbitrary construction budget. Accordingly, some other way to encourage builders to introduce noise and vibration controls remains to be found.

Resilient Isolation of Piping

The lack of either a standard or a certification procedure at the present time leaves only resilient isolation of the plumbing as a means of noise control, but based on the evidence of past installations, this should not be discounted as a design option. Probably the most encouraging possibility was presented in the 1960s by a builder of low-cost, three-story, wood-framed apartment buildings in southern California. In a highly competitive market, he had concluded that making his buildings quieter could be used to economic advantage, so he sought information on how to do just that. He agreed to try a readily available sleeving device in a test to resiliently isolate the plumbing piping from the wood framing and was so pleased with the results of his experiment that he decided to use this procedure in all his future projects.[7]

Since then, similar studies have confirmed that the use of resilient sleeves for noise control need be neither difficult nor costly, and its success requires only the whole-hearted cooperation of the builder. Some examples of successful corrective work and specified work are presented to demonstrate practical possibilities.

Multi-Unit Dwellings.[8] A 1965 call for help in correcting a new and impossibly noisy hotel plumbing system provided an opportunity for on-site analysis that confirmed precisely what was indicated by theory and by laboratory studies. This building comprised eight-story and three-story wings of concrete construction with tile-finished, light-weight unit masonry partitions between guest bathrooms. The minimally designed plumbing system incorporated low-quality fixtures, with flow velocities estimated at 2.6 to 2.8 m/s and piping from common risers solidly grouted into the masonry partitions. The pairs of back-to-back shower risers were tied with a rigid cross-brace for temporary alignment, while bathtubs were light-gauge sheet metal with no damping. The hotel had been acquired by a leading hotel chain and advertised high-quality accommodations, but complaints about excessive plumbing noise were evidently severe enough to merit prompt attention.

The developer was reluctant to authorize any acoustical testing whatsoever but did agree to a limited study, providing any damage to the facility could be confined to a single plumbing stack on one floor. In addition, the tests would have to take place during the hours when guests were least likely to be present. A second-floor section of the low wing was selected, allowing for possible measurements above and below, as remote as possible from other sources of noise and vibration and with the surrounding rooms kept mostly unoccupied.

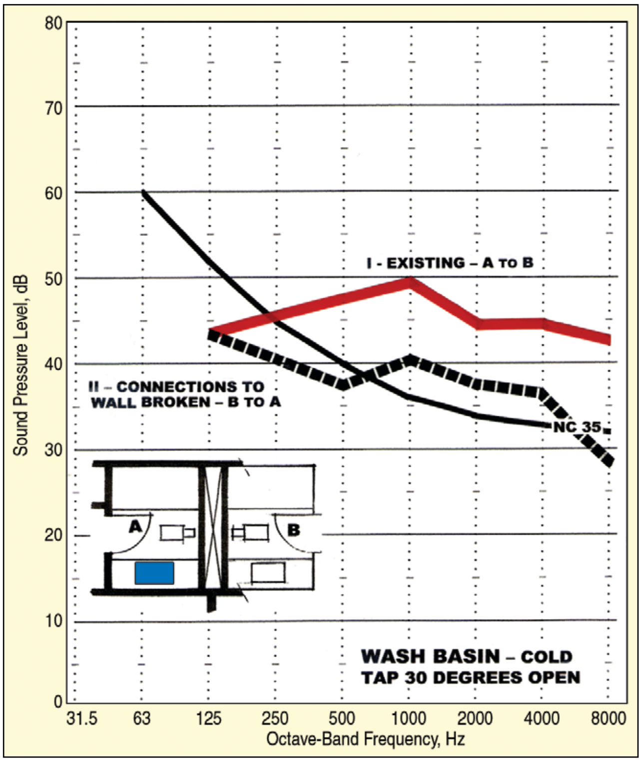

Figure 1. Basin tap, 30° open.

In some studies, it has been helpful to record and play back the audio component to distinguish between airborne and structure-borne noise,[9] but on this occasion, it was not considered necessary. The quite unsophisticated method of measurement, carried out under the watchful eye of the developer's representative, was to run water at a constant rate from a single fixture in one bathroom and to measure the resulting noise levels in the adjacent bathroom. Then the rigid supply piping connections to the adjacent bathroom were isolated, and the measurements were repeated as exactly as possible.

A third set of measurements was also made with the flow rate reduced. For expediency, all measurements were made with a hand-held sound level meter with an octave-band filter. Parallel vibration measurements were started but soon abandoned because of the extra time required and because the noise measurements, which proved to be quite consistent, were considered more significant by the client.

After measuring flow noise in the adjacent bathroom from the existing wash-basin, a resilient connection was inserted in the supply piping, and the drain pipe was temporarily disconnected. For the bath-shower, the wall in the test bathroom was broken out to separate piping from masonry, and the opening was sealed with paper-backed batt insulation to retain most of the airborne isolation between the two spaces.

Piping connections to fixtures in the adjacent bathroom were not broken, but each pipe was chiseled free of the masonry and then sealed airtight with a resilient caulking. With some difficulty, the toilet bowl was tested on a resilient layer to avoid rigid connection to the floor slab. A useful measurement for comparison was also made with a flush-tank toilet that had been installed by the developer in a separate experiment. Results of the more descriptive measurements are summarized in Figures 1 to 5, with the NC 35 curve included for reference.

It was found that a worthwhile improvement from combining the resilient isolation of piping connections and reduction of flow rate was attained for each element, and especially for the bath-shower fixture, where the rudimentary mixing valve was seen as the prime culprit. To separate bath-shower flow noise from water falling in the bathtub, the water was redirected by a hose to a remote drain. While some advantage was found in the crude method of isolating the toilet bowl, it was considered minor compared to the much

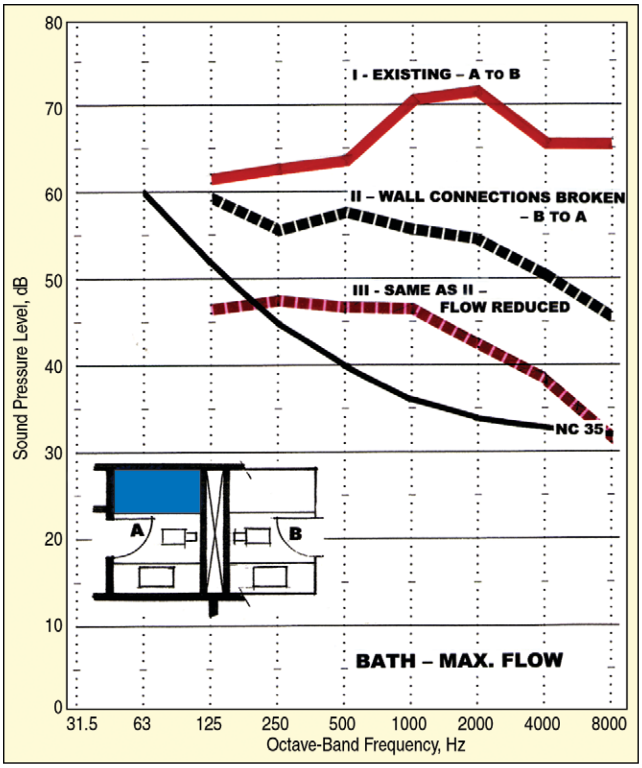

Figure 2. Bath, maximum flow.

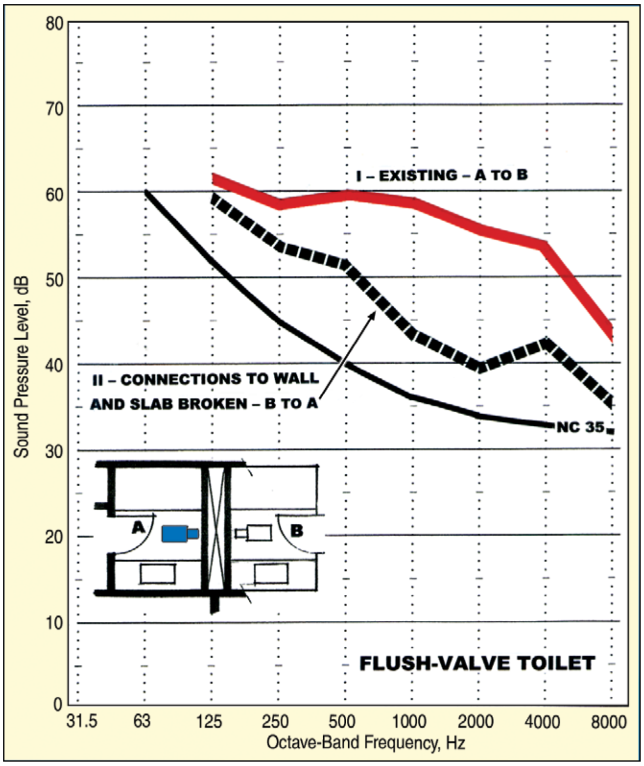

Figure 4. Flush-valve toilet.

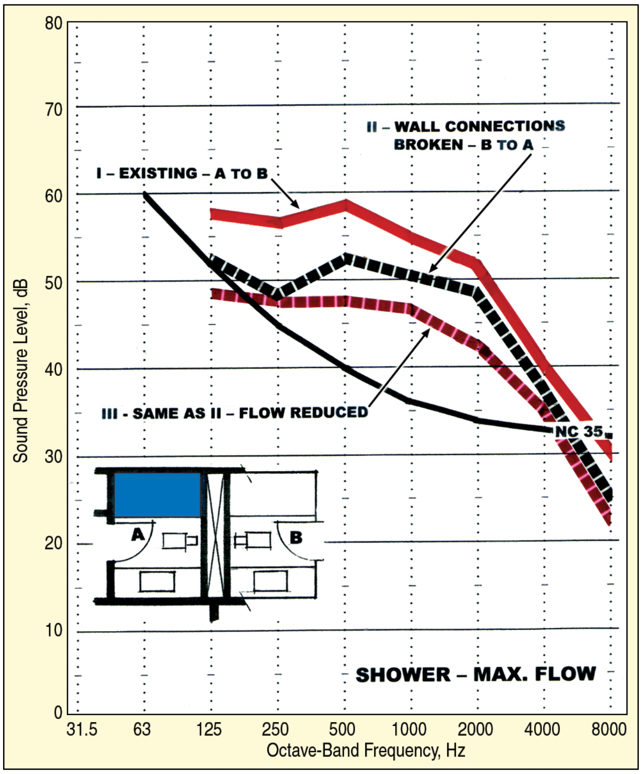

Figure 3. Shower, maximum flow.

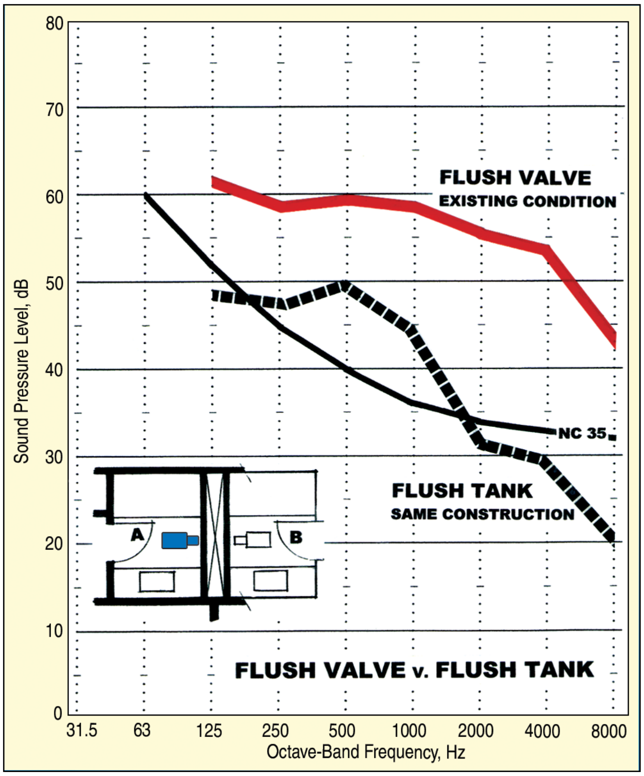

Figure 5. Flush valve versus flush tank.

easier isolation of piping from the walls and was not recommended as an improvement.

Based on these measurements, a systematic remodeling of the guest room plumbing was recommended, in which one stack of rooms at a time would be modified to minimize disruption of hotel activity. As an alternative to installing flexible connections in supply piping, a preferable method was found to be effective – using sleeves of a resilient material at each anchor point or penetration to decouple piping from the structure. How far the developer went in carrying out the recommended corrections is not known, but the examples measured under relatively controlled conditions indicated that even simple changes can be significant when things are bad enough.

Probably the best indicator of the effectiveness of installing resilient isolators was the use of this isolation method for plumbing systems in a succession of new hotels built by the same company along with the fact that plumbing isolation was later incorporated in the hotel standards. Each of these projects was considered to be generally satisfactory, although no site inspections were authorized, and a few isolated examples of inadequate piping isolation could apparently be found after completion. The resilient pipe sleeves have since been used with varying success on new projects of all

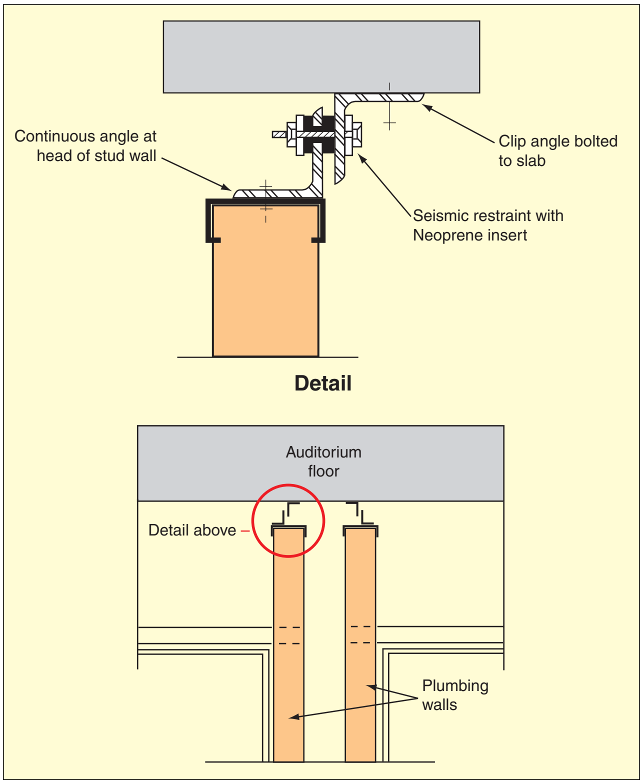

Figure 6. Toilets below auditorium.

descriptions, though unfortunately deleted on some projects in the value-engineering phase, a euphemism for often indiscriminate cost cutting.

Everyday Examples of Plumbing Isolation. From the large number of plumbing noise situations encountered over the years, several obvious comparisons stand out as indicators of good practice. A comparison of two well-used auditoriums provides both a case study for first-hand observation and a commentary on the lack of attention to such matters by the building professions. In the former, rigid piping connections that have been in regular use for almost half a century fill the auditorium with noise whenever a flush-valve is operated. A sign in the washrooms requested "Please try not to flush during a concert," but the recommended corrections still had not been made as recently as two years ago.

In the latter example, two rows of toilets were installed back to back directly below the audience seating area as shown in Figure 6. Since no other suitable location for these spaces was available, the double plumbing wall was resiliently isolated from the auditorium floor using readily available isolator hardware. Unfortunately, no funding was available for measuring successful installations, but the inability to detect plumbing noise in close to an NC 20 environment must be considered an adequate measure of effective noise isolation.

Many unnecessary problems have been investigated, such as tracking down continual flow noise in an executive dining room. This entailed crawling above a plaster ceiling to locate unwanted piping connections and discovering that an installer had jammed a water supply pipe against a conduit tied to the plaster work. As an alternative to crawling in a second time to install a resilient pipe sleeve, a quick remedy was tried – jamming a folded pocket handkerchief between the two elements brought an end to complaints.

In a comparable example, the head of a research group in a single-story on-grade building complained that he heard the noise of every toilet flushing even though he was well removed from the block of wash rooms. A simple investigation showed that the water main entered the building at his office from a noisy pressure-reducing valve directly outside, with piping solidly connected to wall and ceiling. The problem disappeared when the pressure reducing valve was replaced and resilient pipe sleeves were installed at all contact points.

Indiscriminate use of any convenient support for piping or conduit etc. has apparently been a common practice in the building industries. As found in one truly egregious case, a plumbing riser in bath rooms of an older high-rise apartment building had been used in place of studs for supporting lath and plaster walls on successive floors. This allowed easy communication by tapping on the wall in bathrooms several floors apart. In yet another situation, an unstable three-way valve at the second basement level of a hotel shook a pipe riser tied to a guest room wall on the 19th floor. When the valve was activated, the wall shuddered, convincing the occupant that the room was haunted.

It is unlikely that we shall see any improvement in control of building quality for most projects until the trend to "design-build" contracts, where many details of the work are left entirely to the discretion of the builder, runs its course. For the present, one can only hope that in the future, the building owner, the one who holds the purse strings, will come to the conclusion that leaving fine points of construction to the builder without reliance on the supervision of an independent professional may well not justify the promised savings in initial cost.

Special Situations. In extreme cases, large plumbing installations in limited space near rooms needing quiet may require heroic noise isolation methods. One particular remodeling example comprised the addition of extra wash rooms in a theatre directly alongside the balcony seating area. Because of the requirement for flush-valves and concern for the potential of leaks in isolating toilet fixtures, the entire floor of each wash room and related piping was resiliently isolated from the rest of the structure on neoprene mounts as shown on Figure 7. Such installations can simplify large plumbing installations that could otherwise be hard to maintain, but they require close supervision of both floor construction and resilient piping connections.

Wood-Frame Construction

By sheer weight of numbers, the most common situation for plumbing noise and the one affecting the most people is residential, be it a single-family dwelling or a multi-unit complex. The big difference in the two categories is that what may be a trivial issue for a one-family home becomes serious where many users share a common set of pipe risers, and this tends to be even more severe in light-frame construction. The structural potential of wood framing allows for construction of four- and five-story buildings in even the most stringent seismic zones, but the potential for acoustical intrusion from one unit to another is profound.

In addition to speed of construction, wood framing is far more tolerant of unskilled workmanship than other building types. The 'finish' carpenter and other finishing trades are generally skilled in covering inaccuracies and misalignment of framing elements created by the 'rough' carpenter, ensuring a wide range in overall quality from one building to another. Yet with few exceptions, resilient separation of domestic water piping systems from structural framing can be relatively inexpensive and easy to do prior to installing wall and ceiling finishes. By contrast, it will be impossible to correct later without damaging walls and ceiling to get at rigid piping connections.

In the example in Figure 8, replacing rigid metal or plastic pipe anchors on ceiling joists with a resilient sleeve is easy, because they are accessible. Within stud walls, however, they could be inaccessible or hard to remedy even if the wall board is removed. The detail shown in Figure 9 illustrates a recommendation for isolating a noisy bath fixture – a desperation correction that would have to be repeated at least twice for each apartment unit. A neglected refinement that saved the builder a little time and money thus entails a major remodeling costing the owner thousands of dollars.

In the apartment building industry, where litigation against inadequate privacy is fairly common, even minor noise intrusions if documented over a long time have resulted in large court awards for unfulfilled commitments. In a recent California lawsuit, the plaintiff, who just happened to be a judge, compiled " . . . a 504-day tally of minute-by-minute references to toilets flushing, shower doors banging and strains of Beethoven played on a grand piano."[10] The jury awarded damages of over $200,000 against the

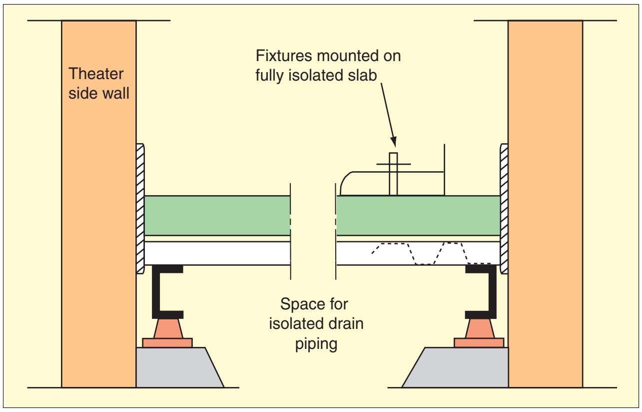

Figure 7. Toilets close to audience.

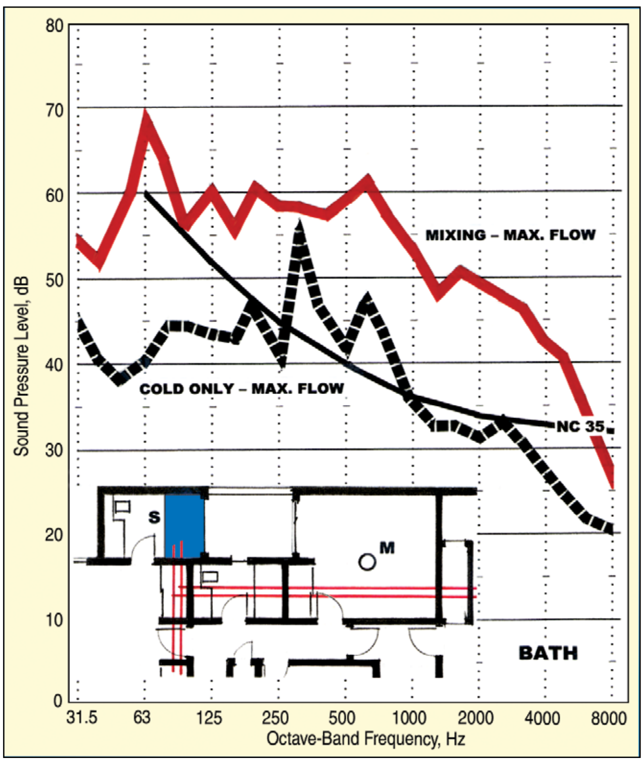

Figure 8. Bath in wood framing.

owner and the neighbors. Clearly, while such a situation might have been avoided, it indicates that members of the legal profession may well be more persuasive than acoustical consultants.

Conclusions

Such issues as the difficulty of avoiding plumbing noise are a relatively minor symptom of the changing nature of the building industry, which has shifted dramatically since around mid-century away from control by the design professions to dominance by the builder-developer. However, there should be no reason for design quality to disappear if the building owner or his construction manager is well enough informed to negotiate appropriate performance standards and the contractual means to ensure that they are fulfilled. But the impetus must originate with the person paying the bills.

In the meantime, while industry standards continue to be debated, making pertinent design information readily available to all branches of the construction industry is still a viable concept. The introduction of simple techniques like control of plumbing noise, with the potential that freedom from intrusion can be a valuable asset in a competitive market, is ripe for exploitation by the building industry. As with the far-sighted apartment builder of the 1960s, when the one doing the selling is convinced that improving quality is good business, other difficulties of design and supervision should disappear.

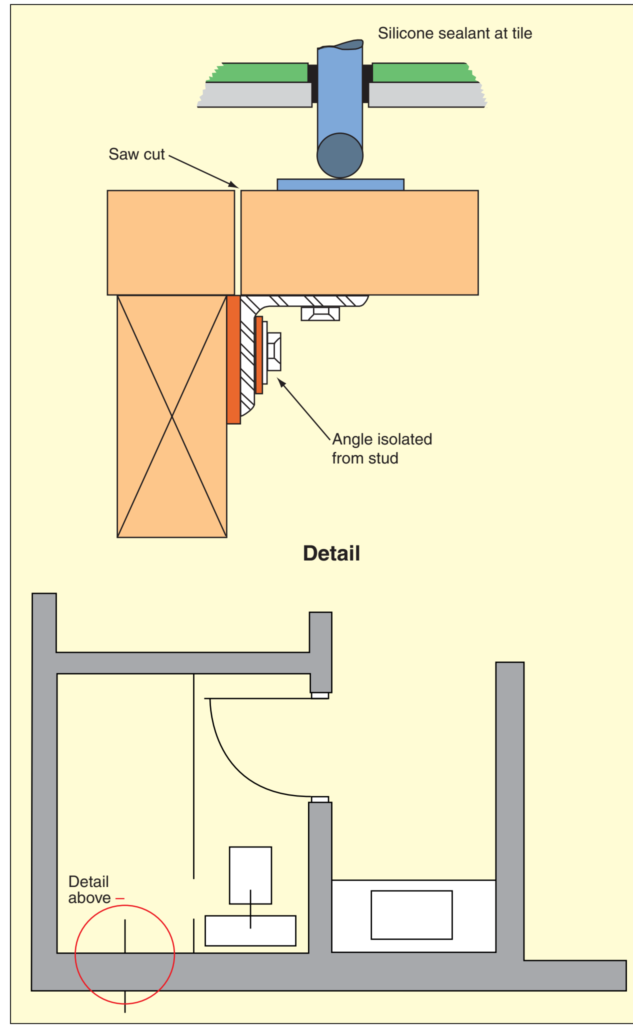

Figure 9. Isolation of existing piping

There is scarcely anything in the world that some man cannot make a little worse, and sell a little more cheaply. The person who buys on price alone is this man's lawful prey.[11]

Acknowledgments

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