Analysis of vibration reduction properties of rail damping under high-speed vehicle moving load

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Rail damping is an active and effective control method for mitigating railway vibration and noise at the source. In order to investigate the applicability of rail damping to high-speed railway, a vehicle-ballastless slab track-bridge coupling dynamic model was established and the vibration reduction effect of rail damping at bridge mid-span, bridge pier and beam gap under a high-speed vehicle moving load was analyzed. The results show that: the max vibration acceleration of ballastless track and bridge with rail damping are obviously decreased, and the duration time of structure vibration is also shortened. The vibration reduction effect of rail damping at bridge mid-span is more significant than that at bridge pier. In the working frequency range of rail damping, the acceleration vibration level of the rail can be reduced by 2-5dB, and the vibration of ballastless track slab and bridge also can be decreased in middle and high frequency range.

1. INTRODUCTION

With the advantages of better track regularity and less maintenance, the ballastless track is widely applied in high-speed railways. But the low elastic concrete track slab brings more serious vibration and noise emissions at the same time, especially when the ballastless track is built on a rigid foundation, such as a bridge. As the vibration of the track system caused by the high-speed wheel-rail interaction forces passing to the foundations, the bridge vibrates and product a kind of noise called secondary structure-borne noise, which aggravates the railway noise pollution. It is imperative to take effective vibration and noise reduction measures in order to keep the harmonious developments between high-speed railway and the environment.

According to recent research on vibration and noise control in urban rail transit and low-speed railway, rail damping is an active and effective control method for mitigating railway vibration and noise at the source. Rail damping is usually composed of rail, damping layer and constrained layer, whose structure is shown in Figure 1. Under the wheel-rail interaction force, the shear effect in damping layer caused by the unequal deformations of rail and constrained layer can convert vibration energy into thermal energy and potential energy. Therefore, the rail vibration is reduced. Andrew Parker and Conrad Weber set the damping material on the rail waist and rail bottom on the NSW metropolitan rail network in Australia. The field test results show that the rail damping can reduce the rail noise of 1.5dB [1]. Field tests about vibration reduction property of rail damping uses on an urban rail transit carried out by Pengbo Wei and He Xia show that the acceleration of the rail waist can be reduced by 6dB with damping rails [2]. Linya Lui analyzed the vibration response of rails with and without damping material on the waist under a constant force, and discovered that rail damping can reduce the vibration of the rail effectively [3]. Nowadays, rail damping has been used in urban rail transit and low-speed railways successfully, but literature

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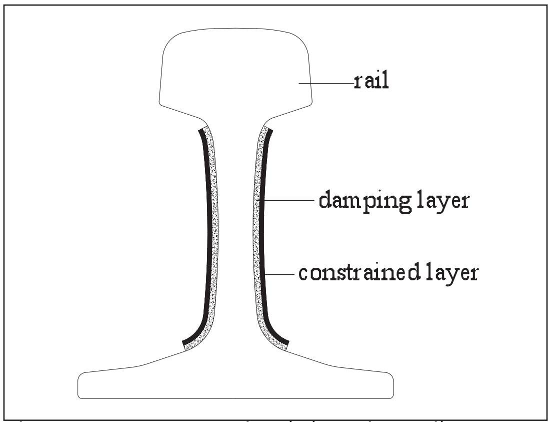

Figure 1. Constrained damping rail

focussing on vibration reduction property of rail damping for high-speed railway is not common.

In this paper, a vehicle-ballastless slab track-bridge coupling dynamic system is established. Under high-speed vehicle moving load, vibration acceleration of this system with and without rail damping are compared to study the vibration reduction effect of rail damping for a high-speed railway.

2. VEHICLE-BALLASTLESS SLAB TRACK-BRIDGE COUPLING DYNAMIC MODEL

2.1 VEHICLE MODEL

The parameters of CRH2 high-speed train are used in vehicle modeling. The vehicle is regarded as a rigid body with 31 degrees freedom (except nodding of the wheels), neglecting the elasticity and torsion deformation. The connections between car body, bogies and wheels in the model are simplified as spring-damping suspensions, and the nonlinearity of the spring is ignored.

2.2 BALLASTLESS SLAB TRACK MODEL

CRTS|ballastless slab track on bridge is composed of rail, fastener, track slab, CA mortar layer, bed plate and sliding layer. The rail type adopted in this paper is 60kg/m. The length of a standard track slab is 4.926m and the gap between two track slabs is 70mm. Rail, track slab, CA mortar layer and bed plate are simulated by entity element, which can consider the shear deformation effectively. The spring-damping element is used to simulate the fastener and sliding layer. The parameters of the slab track are shown in Table 1.

The ballastless slab track system with rail damping has the same foundation as the one with standard rail. As the thickness of the damping layer is 3mm and the constrained layer is 2mm, which can be ignored compared to the whole track-bridge system, shell element is used to simulate the damping layer and the constrained layer. The shear modulus of the damping layer is 6.75 MPa.

Track irregularity is the excitation source of wheel-rail coupling vibration. To reflect the actual situation, this paper sets the track irregularity spectrum of Chinese Shanghai-Hangzhou High-speed Railway at a speed of 250km/h on

Table 1. Design Parameters for CRTS¢ÒBallastless Slab Track

structure	density(kg/m^3)	Young's modulus(N/m^2)	Poisson's ratio
t rack slab	2500	3.55×1010	0.2
CA mortar layer	2450	7.00×109	0.167
bed plate	2500	3.30×1010	0.2

the track model.

2.3 BRIDGE MODEL

The vibration characteristics of a ballastless slab track system at bridge mid-span, bridge pier and beam gap between continuous beam and simply supported beam are not all the same. In order to analyze the vibration reduction properties of rail damping at different positions on bridge, a (60+100+60) continuous beam bridge +32m simply supported beam bridge is established to meet the analysis requirement. Structure parameters of the continuous beam bridge with variable sections come from one bridge on Chinese Beijing-Shanghai High-speed Railway. The material of the bridge beam is C50 concrete, which is the same as the ballastless slab.

2.4 SYSTEM COUPLING

The interaction between rail and wheels is calculated according to the Hertz nonlinear contact theory. Sliding layer is the connection between ballastless slab track and bridge. The vehicle-ballastless slab track-bridge mechanical model based on the wheel/track coupling dynamics [4] is shown in Figure 2, and the finite model established by ABAQUES/CAE is shown in Figure 3.

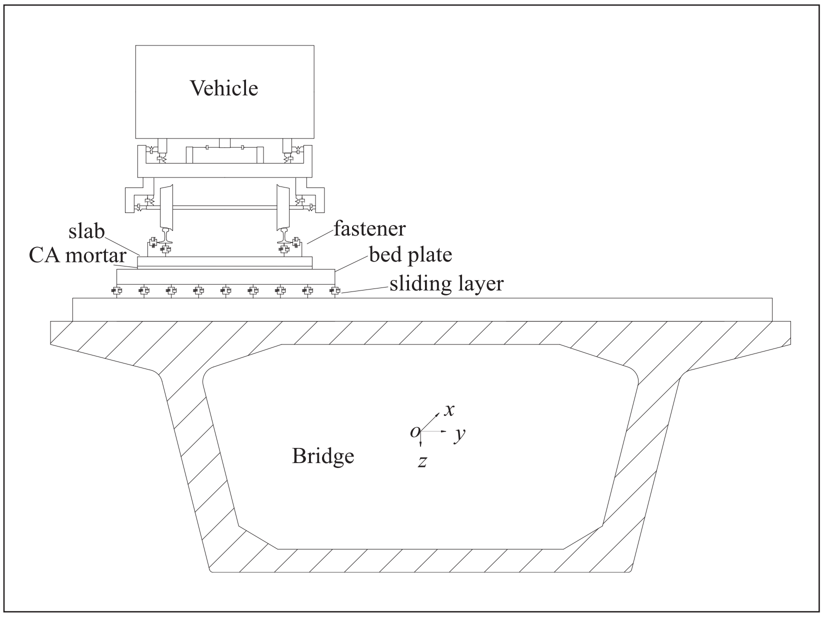

Figure 2. *Vehicle-ballastless slab track-bridge mechanical model*

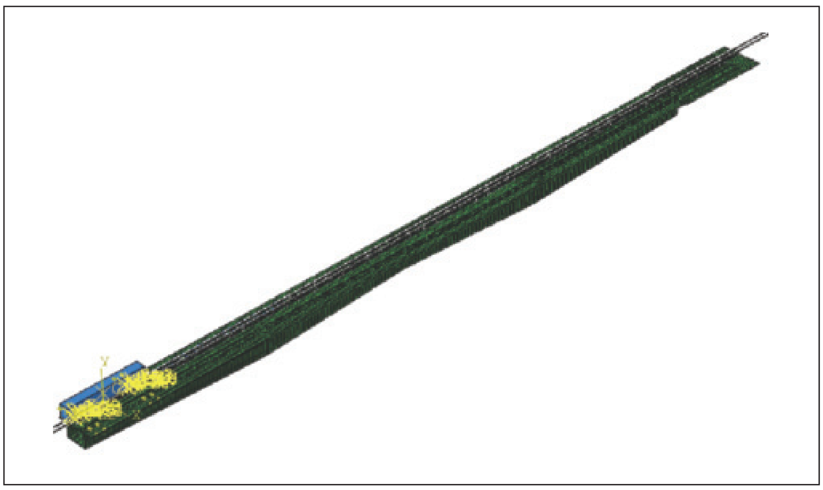

Figure 3. *Vehicle-ballastless slab track-bridge coupling dynamic model*

3. ANALYSIS OF VIBRATION CHARACTERISTICS IN TIME-DOMAIN

Based on the vehicle-ballastless slab track-bridge coupling dynamic model established in Section 2, the vibration characteristics of the dynamic system with and without rail damping at 250km/h are calculated, including the accelerations of rail, track slab and bridge beam at mid-span, bridge pier and beam gap (Figure 4).

Table 2 shows the maximum accelerations of the track system and bridge with and without rail damping at different analysis positions as the vehicle passes the bridge.

It is known from Table 2 that maximum acceleration of rail damping is smaller than that of standard rail. Using rail damping, rail acceleration can be reduced by 19.58% at mid-span, 3.71% at bridge pier and 8.55% at beam gap. As the rail vibration is reduced, the vibration energy passing to the track slab and bridge decrease at the same time. Setting rail damping at bridge mid-span can get the best vibration reduction effect; however, the vibration reduction effect is inconspicuous when the rail damping is set at bridge pier, mostly because the stiffness at bridge pier is greater than that at mid-span. As the constrained structure of rail damping increases the flexural rigidity of the rail section, rail displacement relative to the bridge surface decreases too.

Figures 5 to 10 show the acceleration-time curves of the dynamic system with and without rail damping when the vehicle passed the bridge mid-span.

It can be seen from Figure 5 to Figure 10 that under the high-speed vehicle moving load, the acceleration peak values of the track system and bridge with rail damping is much smaller than that of track system with standard rail. The figures also show that the vibration dissipation of track system with rail damping is faster than that of track system without rail damping. Those disciplines summarized above are also appropriate for the vibration characteristics of the track system and foundation at bridge pier and beam gap, so their acceleration-time curves are omitted here.

4. ANALYSIS OF VIBRATION REDUCTION PROPERTIES IN FREQUENCY-DOMAIN

Transform the acceleration-time curves of track system and foundation with and without rail damping into 1/3 octave curves using Fourier Transformation

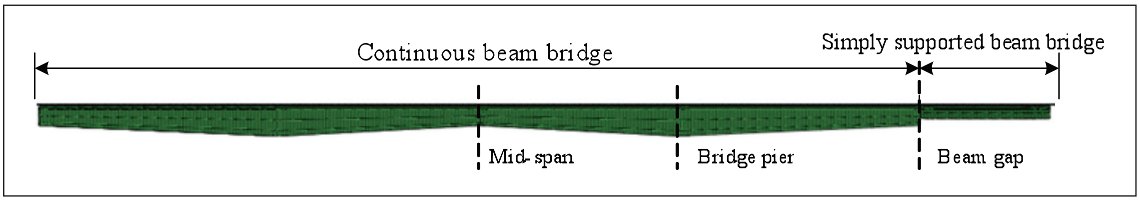

Figure 4 Analysis positions on the bridge

Table 2 Max Accelerations of the Dynamic System

	Mid-span		Bridge pier		Beam gap	
	standard rail	damping rail	standard rail	damping rail	standard rail	damping rail
rail acceleration /g	182.916	147.103	188.221	181.238	186.667	170.697
track slab acceleration /g	7.056	2.807	7.383	6.239	9.598	8.530
bridge acceleration/g	0.155	0.089	0.174	0.104	0.127	0.057
rail displacement (relative to bridge surface£©/mm	0.949	0.862	0.875	0.754	0.738	0.588

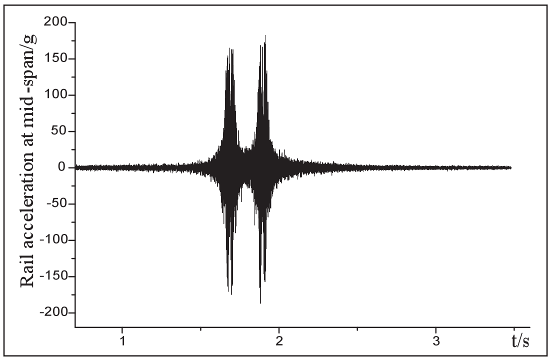

Figure 5. Acceleration-time curve of standard rail

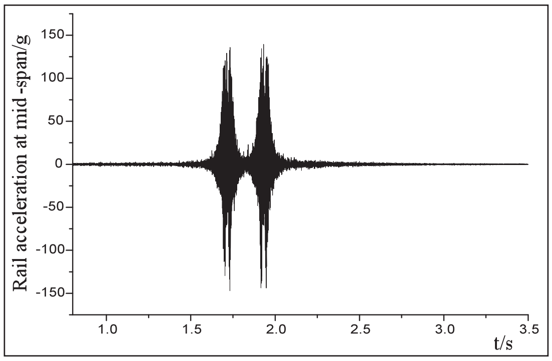

Figure 6. Acceleration-time curve of damping rail

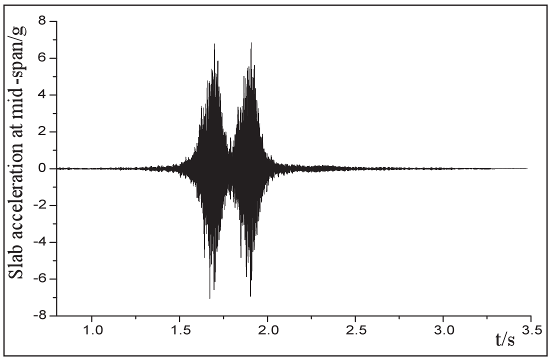

Figure 7. Acceleration-time curve of track slab with standard rail

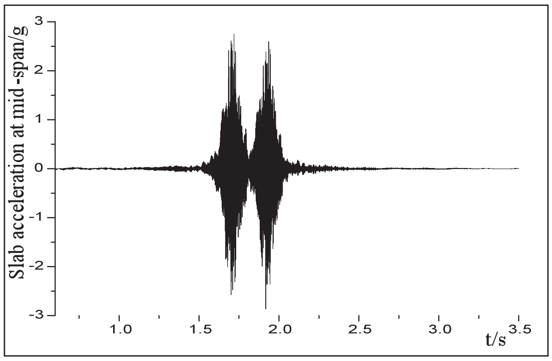

Figure 8. Acceleration-time curve of track slab with damping rail

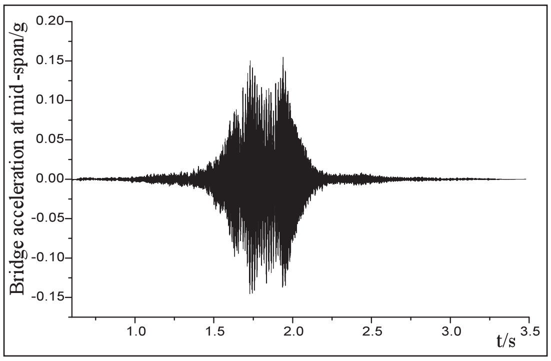

Figure 9. Acceleration-time curve of bridge with standard rail

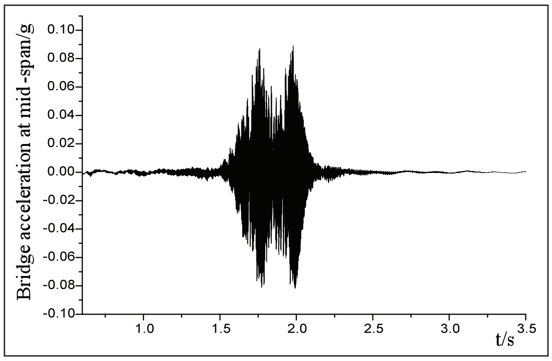

Figure 10. Acceleration-time curves of bridge with damping rail

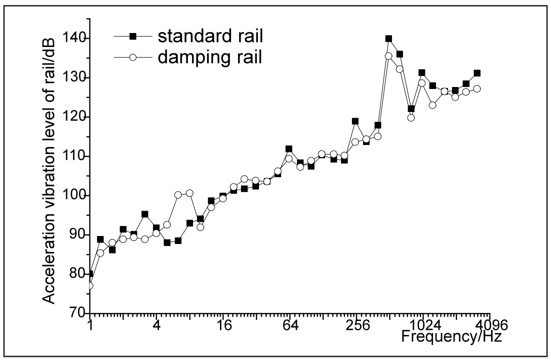

Figure 11. Acceleration vibration level of standard rail and damping rail at bridge mid-span

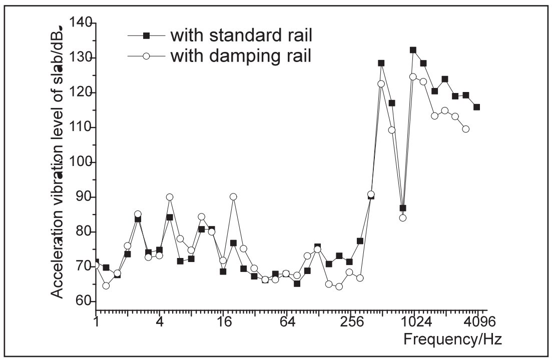

Figure 12. Acceleration vibration level of track slab with and without damping rail at bridge mid-span

[5]. The comparison of acceleration vibration level between standard rail and rail damping at bridge mid-span is shown in Figure 11. The vibration characteristics in frequency-domain of ballastless track slab and bridge are

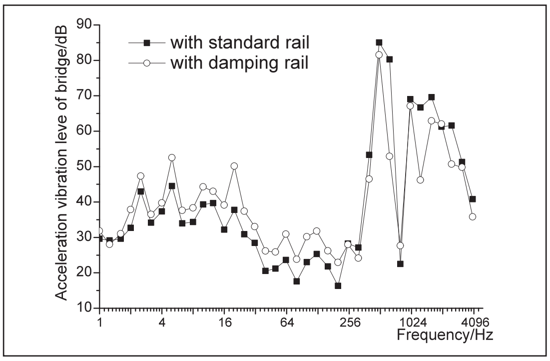

Figure 13. *Acceleration vibration level of bridge with and without damping rail at bridge mid-span*

shown respectively in Figure 12 and Figure 13.

In Figure 11, the acceleration vibration levels of standard rail and rail damping are all increasing as the frequency is increasing. In the low frequency range 0-250Hz, the acceleration vibration level of rail damping is almost the same with that of standard rail, even greater than the latter one at some frequencies. In the frequency range 250-4000Hz, rail damping can decrease the vibration level of rail at mid-span by about 2-5dB. It can be seen from Figure 12 and Figure 13 that vibration of ballastless track slab and bridge can be decreased significantly with rail damping in middle and high frequency range, but the vibration of bridge in low frequency is amplified. The lowest working frequency for the damping rail is 250Hz under high-speed vehicle moving load.

5. CONCLUSION

In this paper, a vehicle-ballastless slab track-bridge coupling dynamic model is established and the vibration reduction effect of rail damping at bridge mid-span, bridge pier and beam gap under high-speed vehicle moving load is analyzed. Through the analysis and comparison, some conclusions can be drawn as following:

(1) Compared to the track system with standard rail, the peak value of vibration acceleration of track system and bridge with rail damping are decreased. Using rail damping can reduce the vibration responds of ballastless track system and bridge, and the duration time of structure vibration also can be shortened.

(2) Setting rail damping at the bridge mid-span can reduce the vibration of rail, track slab and bridge obviously. But the vibration reduction effect is not significant at bridge pier as the stiffness here is greater than that at mid-span.

(3) The lower limit of working frequency for rail damping under high-speed vehicle moving load is 250Hz. In the working frequency range of rail damping, the acceleration vibration level of rail can be reduced by about 2-5dB. And the vibration of ballastless track slab and bridge can be decreased significantly with the rail damping in middle and high frequency range.

ACKNOWLEDGEMENTS

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HELICOPTER VIBRATION PROGRESS

Sikorsky Aircraft and Lord Corporation have announced the successful completion of flight demonstration testing of the Hub Mounted Vibration Suppressor (HMVS), a new technology aimed to reduce vibration on helicopters. The demonstration was part of an effort to address the challenge of crew fatigue and reduced equipment reliability and readiness that are caused by helicopter vibration. The two companies collaborated on the HMVS flight demonstration at the U.S. Army's Aviation Applied Technology Directorate (AATD) at Fort Eustis, Virginia, in March. The flight test, completed in March 2014, was performed as part of the Active Rotor Component Demonstration (ARCD) program. The ARCD HMVS flight test was a joint effort among AATD, Sikorsky Aircraft and Lord Corporation. Flight testing on AATD's UH- 60A BLACK HAWK helicopter included progression from a hover to 150 kts, autorotations and 60-degree angle-of-bank turns. Successful testing in the maneuvering conditions proved the HMVS technology suppressed vibration even in the most dynamic flight conditions. The HMVS cancels the largest vibratory loads near the source of the vibration, which is the main rotor hub, thus keeping the loads from propagating into the airframe. In preliminary flight testing, the HMVS was found to reduce vibration significantly, with a 30 percent weight reduction. More info: Sikorsky Aircraft Corporation, Stratford, Connecticut 06614- 1385, USA

25% OF UK WORKFORCE AT RISK OF NOISE INDUCED HEARING LOSS

A quarter of the UK's workforce are at an increased risk of noise induced hearing loss because they use headphones while at work, according to a study from an audio technology company. In a survey of 2000 UK workers, Limitear found that British workers listen to an average of 110 minutes of audio in the workplace, and a further 92 minutes outside of work hours. In total, an estimated 7.6m people are exposed to over 3.5 hours of reproduced sound each day. European regulations stipulate that workers should not be exposed to average noise levels of more than 85dB, over an eight hour period. However, when listening to an MP3 player at full volume, this generates 100dB of sound, meaning it should only be istened to for a maximum of fifteen minutes or risk hearing damage. The survey also found that despite 48% having concerns about loss of hearing, 79% of respondents were unaware their employer is legally required to protect them from hearing loss. Health and Safety Executive noise and vibration specialist inspector Andrew Thompson said that employers retain responsibility for their workforce even in cases where employees are controlling the volume of audio on their own devices. "As well as potentially contributing to hearing damage the uncontrolled wearing of personal headsets in the workplace may also have safety implications because of an impaired ability to communicate or hear warnings, alarms, moving vehicles etc," Thompson said. "Employers allowing staff to use their own headphones or earphones must ensure that they're adhering to regulations and sufficiently protecting staff."

NEW LOUDSPEAKER SOLVES CHINESE NOISY DANCING PROBLEM

To reduce disturbance caused by loud music played by older residents who congregate outdoors to dance, researchers at Shanghai's Fudan University have developed a speaker system that can reportedly target sound to a specific area and not be audible elsewhere. The invention may be the compromise that will satisfy both the dancers - usually middleaged pensioners and the elderly who play music for their group dance in public spaces - and the residents who are disturbed by the noise from the activity, which usually takes place in the early morning or evening. Researchers at Fudan University are developing a "directional loudspeaker" as a solution, the Beijing Youth Daily reports. Professor Ma Jianmin, from the university's department of engineering science and mechanics, said the speaker "effectively contain[s] sound waves in a certain area". Ma said the device could also be used in other public spaces, like bus stations or airport waiting areas, or to broadcast messages to a specific group of people without creating extra noise. The Youth Daily said the speaker system cost several hundred to a few thousand yuan, but made no mention of when it would be commercially available. Last month, in Wenzhou city, a residential committee spent 260,000 yuan on a "treble cannon" that emitted a loud, unbearable noise to disrupt dances. Last August, a man in Beijing sent his three Tibetan mastiffs to scare away dancers near his home. Last April, people threw water at the dancers in a residential compound in Chengdu , Sichuan province.

EARLY MORNING NOISE

A council is investigating a pair of young brothers for noise pollution after their neighbours complained they get up too early in the morning and play! Euan and Charlie Ducker, aged two and four, live in a flat and like most young children are up at the crack of dawn. The problem is exacerbated by the fact that the floors in the Duckers' second floor flat are uncarpeted, so the sounds of the lads pushing their toys along the floorboards is amplified in the properties below. The boys' father Andrew, 34, branded the investigation 'ridiculous'. He said: "The boys are just normal kids trying to play. They don't realise it's early and they are being loud." Andrew is jobless and says he cannot afford to carpet the hallway. He fears his family could be evicted out if the boys' behaviour is ruled as anti-social. Selby Council in North Yorkshire said it had a duty to investigate any noise complaint and it is trying to find a solution. It denied threatening eviction.

NOISE COMPLAINTS ABOUT SCHOOL SPORTS

Aylesbury Vale District Council's environmental health team are working with Mandeville School and neighbours following complaints of noise from its multi use games area in the evenings and at weekends. The artificial grass pitch was opened in 2012 by West Ham and England footballer Sir Trevor Brooking. The school's business manager Zoe Brogan said that plans are in place to install an accoustic curtain, which will help protect against excess noise. She said: "We've always been mindful of our neighbours and we're doing everything practically possible to make sure we're not burdening the residents with our noise." A spokesman for Aylesbury Vale District Council said: "We have been investigating complaints from nearby residents regarding noise from the use of the artificial grass pitch outside of school hours, in the evenings and at weekends. "We are currently working with Bucks County Council and the school to improve the situation."