Maintenance and Protection of Bells

Sixth Framework Program of the European Community
RESEARCH DIRECTORATE-GENERAL
Integrating and strengthening the European Research Area
Co-operative Research Project COOP-CT-2005

Contract Number:	015684
Duration:	1. Oct. 2005 to 31. March 2008
Coordinator:	University of Applied Sciences Kempten

Report: **Final Activity Report**

37 pages

Date: 30.07.2008

Prof. Dr.-Ing. Andreas Rupp / Coordinator

Content **Page**

1 Summary

Church bells are both musical instruments strongly connected to the European culture and technical structures exposed to severe loading conditions during ringing. Many famous bells being in service for centuries are damaged by cracks and wear, leading to a severe loss of valuable cultural heritage and require high efforts and cost for repair.
The system bell-clapper-belfry, being in service under ringing conditions different from region to region, has been developed over the centuries, mainly based on intuition and tradition. The technological mechanisms and reasons for damages are widely unknown. For the 9 involved SME bell/clapper manufacturers the elaboration of field procedures and respective data to reduce damages is most decisive:

- The bell is a component of the bell system with yoke, clapper, fixtures, dampings and motor. The components of the system and their setup determine the sound of the bell and the risk for damages.
- Each bell system is unique musical instrument, and thus needs to be evaluated individually. In many aspects no general rules and recommendations can be provided.
- The elaborated knowledge with the reliable new procedures and data allow the specialists to set the ringing conditions in the smoothest way achieving at the same time high musical quality.
- A new professional service on historical and new bells opens a new and strong business branch to the European bell foundries reducing costly damages and the risk for personal and people by damaged bells or clappers.
- Product reliability arguments on damages of new or repaired bells shall be defined more clearly and prevent the foundries from pretensions for damages out of their responsibilities.
- A European Competence Centre for bells to be established at the University AS Kempten is in preparation, to ensure the dissemination of the results to the public.
- Project to prevent culturally and historically important bells from damage are planned.
- Open questions concern the optimisation of the cast process to reduce the risk for failures especially on large bells and the quality control of repair measures e.g. welding.

The project strongly supports:

- the protection of European cultural heritage, by holding over the life of a large number of bells, by optimisation of ringing conditions, professional services for necessary repair measures,
- reduction of risk due to bells/clapper damage,
- maintaining a higher musical quality.

The achievements of Probell will be used and disseminated by the following planned activities.

- A European Competence Centre for Bells will be found at the University AS Kempten, to keep the know how with the responsible scientific personal. This centre will be the address for any question of the partners during the implementation of the new technologies. It is financed by the bell foundries, the Uni Kempten and project funds.
- The project webside www.probell.net will be kept and used as a forum of contact and communication for all bell interested.
- Each partner will apply the methods and tools and give feed back by this work;
- A tool box will be developed and offered to the partners, which contains the necessary experimental and analytical tools ;
- Uni Kempten will prepare a special seminar to train the partner stuff in the application of the experimental and analysis work;
- A symposium to present the work to the public, the bell experts, the churches and the cultural heritage responsible is planned for mid of 2009;
- A seminar for bell experts, not being partner of the project will be prepared and offered by University AS Kempten;
- The activities of the consortium will aim on the introduction of the technology of the determination of the musical fingerprint for cultural and historical important bells:
- New research project shall be proposed for the optimisation of the cast process of bells and the evaluation of repair measures e.g. welding.

2 Objectives

Church bells are both musical instruments strongly connected to the European culture and technical structures exposed to severe loading conditions during ringing. Many famous bells are in service for centuries and on numerous bells damages occurred due to the continuous ringing. Thus the musical instrument may have been destroyed or even when repair measures could be taken, historical ornaments and inscriptions were lost in spite of high cost for repair or recasts. Fracture of clappers may lead to dangerous fall down of the heavy steel pieces.
The system bell-clapper-belfry system has been developed over the centuries, mainly based on intuition and tradition. Reasons for the damages and the influence of main parameters are widely unknown. For the 9 involved SME bell foundries and clapper manufacturers it is of major interest, to develop

1. reliable procedures and subsequently the
2. equipment for a predictive diagnosis of damages on bells and the
3. tools to set up the bell system for most smooth ringing conditions.

These developments are used to:

- open a new and strong business branch by the European bell foundries by a professional service based on the elaborated knowledge in competition to non-professional amateurs,
- reduce damages and thus high cost for the parishes and the bell foundries,
- reduce the risk for personal and people by damaged bells or clappers,
- set the ringing conditions in the smoothest way achieving at the same time a high musical quality for a better acceptance of bell ringing noise to the neighbourhood of churches,
- prevent the foundries from pretensions out of their responsibilities for damages of new or repaired bells,
- new standard for the installation of bells similar to the newly defined DIN4178 for church towers with bells.

Well experienced RTD performers shall elaborate under the guiding expertise of the 9 European bell foundries, the clapper manufacturers and the involved bell expert as representative of the endusers the necessary knowledge with the respective data and define a new state of the art by means of measurement and testing in combination with computer simulation both of the dynamical effects and the local phenomena according to the latest state of art. Long term ringing tests on bells and accelerated specimen tests taking into account the different European ringing cultures will provide the necessary evaluation data.

The objects of the project are:

- a parameterized model of the system bell belfry including the main parameters, which determines the loading of the bell adaptable for the different European ringing cultures,
- data about the wear and the life of the bell materials under well defined ringing conditions based on parameters, to be identified by the model,
- concept for the qualification of the musical quality of a bell relative for different ringing conditions,
- a guideline to adjust for optimum smooth, low damaging ringing conditions with a high musical quality,
- a guideline to identify initiating damage on bells and clappers based on sound and clapper acceleration analysis;
- demonstration of the parameterized model, the strength data, the concept on 3 selected historically important bells in the towers;
- an information package for other bell experts and amateurs in the parishes.

A user friendly instrumentation set and software package will be elaborated after the project for the bell inspectors for the application of the new knowledge.
Therefore the project strongly supports the protection of European cultural heritage and the results are applicable and important also for other products e.g. cast engine blocks. This is emphasized by the following letters of compliments by ministries of cultural heritage and the churches.

3 Contractors

Partic Role	Partic. Type	Participant ame	Participant short name	Country
CO	RTD	University of Applied Siences Kempten	Uni Kempten	DE
CR	SMEP	Glockengießerei Bachert Karlsruhe GmbH	Bachert	DE
CR	OTH	Fonderia Daciano Colbachini & Figli *	Colbachini	IT
CR	SMEP	Cornille-Havard SA	Cornille Havard	FR
CR	SMEP	Johann Grassmyr	Grassmayr	AT
CR	SMEP	John Taylor Bellfounders LTD	John Taylor	GB
CR	SMEP	Campanas Quintana S.A.	Quintana	ES
CR	SMEP	Glocken- und Kunstgießerei Rincker GmbH & Co KG	Rincker	DE
CR	SMEP	Glocken- und Kunstgießerei A. Rüetschi AG	Rüetschi	CH
CR	SMEP	ROSSWAG GmbH	Rosswag	DE
CR	OTH	TÜV Süddeutschland GmbH	TÜV-SÜD	DE
CR	OTH	Glockeninspektion Erzbistum Freiburg	BellExpert	DE
CR	RTD	University of Ljubjana, Faculty of Mechanical Engineering	UNI Ljubjana	SLO
CR	RTD	University of Padova, Departm. of Mechanical Engineering	Uni Padova	IT

* closed down in Feb. 2007

4 Activities 1.10.2005 to 31.3.2008

4.1 Events and special Activities

Meetings

- Midterm meeting on 16. and 17. Oct. in Villedieu les Poelles, France
- Final Scientific Committee Meeting on 30. Jan. To 2 Feb. 2008 in Monastry St. Lamprecht Austria
  as Scientific Auditor Prof. V. Grubisic, Reinheim, being auditor of FP5 and member of the Academy of Sciences evaluated during the 3 days the work of the scientists
- Numerous bilateral meetings in Kempten, Ljubljana, Padua, Innsbruck, Sinn, Karlsruhe and Aarau between the partners and the Universities
- Final Meeting of the Consortium on 21. To 23 July in University AS Kempten

Logo and Webside

- News was provided continuously on the project webside www.probell.net about progress of project and events in the project

Press conferences

- 8.June 2006 in Kempten
- Multiple pre conferences during the demonstration measurements on famous bells

Trade show participation
- Materialica Munich, 10. – 12. Oct. 2006

Presentations and publications
- Presentation of PROBELL on 14. Kolloquium zur Glockenkunde on Greifenstein Castle on 6. – 8. Oct. 2006
- about 50 articles in different newspapers

Television, Radio
- Numerous reports about the project in german, Austrian and European television
- Film about the project by Bayern 2, Swiss and Euronews television
- Numerous reports about the project and special events in many radio programs

4.2 RTD Work

4.2.1 Definition of technical problem

Bells are loaded during service by the clapper impact.
- The intensity of the clapper impact is determined by the global dynamic parameters of the system bell – clapper – clapper guidance – yoke – belfry – and motor with its drive wheels. The resulting local phenomena of the contact of clapper and bell determine the energy transferred into frictional dissipation and in the deformation of the bell and its sound emission. The bell starts to ring and according to its elastic and material damping conditions as well as emitted energy the sound of the bell is created.
- The local frictional conditions determine the local wear and material disruption. The decisive parameters are the clapper material, its shape, its centre of energy during swinging, the guidance and the impact intensity.
- The bell is exposed to the material deformations during swinging which are highest during and directly after each clapper impact. The continuous deformations lead to a fatigue of the material.
- The clapper is loaded during the impact mainly determined by its centre of energy during swinging.
- The contact conditions are changed depending on the elasto-plastic material behaviour of the clapper material, a forged steel and also the transient wear on the bell.
- The musical quality finally is a result of the local contact in terms of time, intensity, cross section and local damping and is determined by the richness of the spectra of the emitted sound.

This very rudimentary description of the technological problem already demonstrates, that the phenomena under investigation, the damages on bells requires sophisticated scientific investigations on the one side and on the other side it is of greatest importance to include the field experience of the bell specialists, to be able to evaluate the challenging analysis results themselves.

4.2.2 Concept of work plan

The concept of the work plan which is shown in Fig. 1, therefore is organised in several work packages:
WP1 Review of **field experience** and knowledge about the most decisive parameters on the damage of bells by systematic and harmonised collection of experience from the bell founders and experts which will result in a detailed measuring and test plan, with the parameters to be set on the bell systems available for the project.;
WP2 **Materials for investigation:** Set up of at least 10 different bell-clapper-belfry systems with different parameters in a sound deadening hall on which parameters e.g. different European ringing conditions, wood or steel yoke and belfry and clappers can be varied.;
WP3 M**easurement procedures** will be developed, of local stresses on bells and clapper, accelerations and sound pressure, which subsequently will be applied to all bell systems under investigation in laboratory or tower. An engineering procedure will be developed to determine

the dynamic characteristics of bell with yoke and clapper. Developing analysis tools for an automated presentation of the relevant results of the measurements in view of damage and musical quality. **Measurements** will be performed of local stresses, dynamic quantities and sound pressure under real ringing conditions under variation of parameters decisive for the damage and the sound, especially clapper material, shape, weight and balance conditions on the different systems. The measured data will be analysed and presented in a comparable way, to determine the influence of the changed parameters on the local load/ damage and the musical quality.

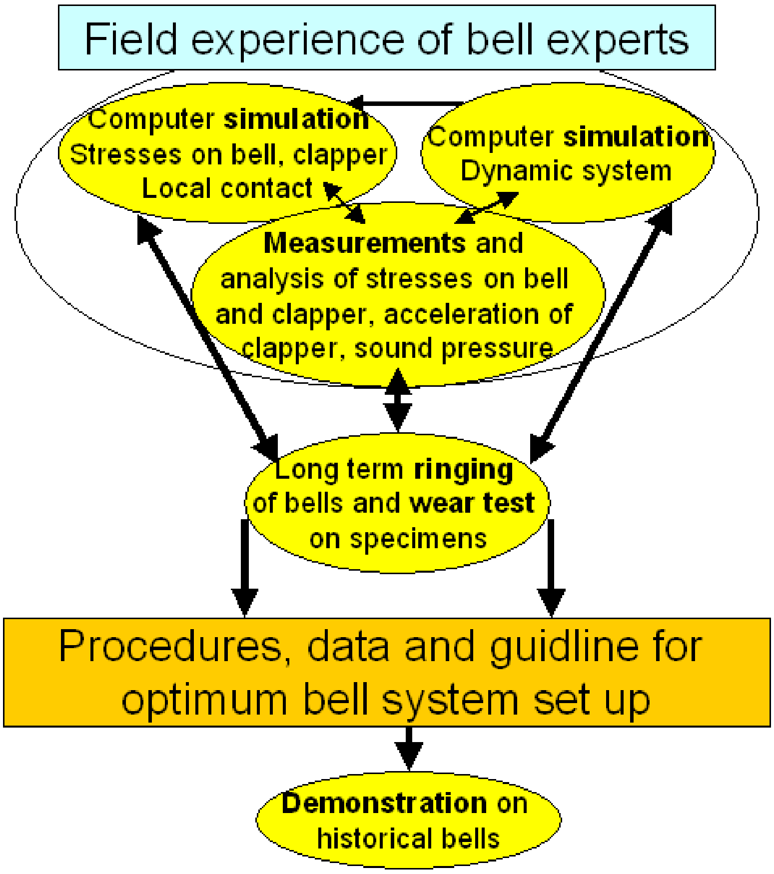


Fig. 1 Concept of work plan

WP4 Computer modelling and **simulation of global bell systems**, to determine the dynamic behaviour of the systems based on the dynamic characteristics of their components. The measured dynamic quantities of the bell systems under investigation are used as input for these models and others for their verification. The main task of this simulation is, to develop the capability to, to realistically simulate the clapper bell contact intensity based on the global parameters of the bell system components.
WP5 **Simulation of the local phenomena** during ringing to determine the influence of the individual parameters. These computer simulations are verified by the measurements on bell systems for selected parameter sets. Subsequently the verified models are used to calculate the influence of other parameter sets. The main task of these simulations is, to correlate the observed wear during the ringing tests, with local load and stress conditions. These computer modelling is subsequently applied for the design of experiments on small material specimens, on which in dynamic test rigs the complex contact conditions should be realistically simulated, and faster and simpler and thus more wear testing can be performed;
WP6 Actual wear and damage investigations can only be performed on real bell systems by continuous ringing. Only a very restricted number of such high effort tests can be performed. About 12 long time **ringing tests** on individual bells will be carried out to monitor the wear for selected parameter sets (clapper characteristics, angularities) until the local wear exceeds critical values or even until the bell is destroyed. The parameters will be set different on each clapper contact side, so that 2 tests can be performed on each bell. During certain periods of

the bells´ life the measurements will be repeated, to determine, whether the dynamic system changes with the developing wear. Due to the variety and high number of parameters additional accelerated **wear testing on specimens** under test parameters defined by the simulations under point 5 is carried out.

WP7 Determination of parameter influences on the different kinds of damage taking into account the musical conditions derived from the sound measurements. **Evaluation and verification** of the findings by the experts;

WP8 **Demonstration** of the developed procedures and data on selected famous historical bells and valuation of their todays ringing conditions. Presentation and publication of the findings of the research as examples on the selected famous bells to a broad audience.

WP9 The **Publication** of the results of the experimental and numerical work packages is of special importance for the introduction of the findings to the daily work of the anticiopated new services to be provided by the bell foundries. It is necessary to explain the highly sophisticated research work to mainly non-technical potential customers in the parishes and the ministries of heritage. Therefore a well defined work package is planned with the aim to prepare information packages about the new knowledge, the new methods and data, to be provided to technicians as well as to amateurs.

According to this concept the individual work packages lead to the following deliverables:

Tab 1: List of deliverables

Deliverable Noi	Deliverable title	Delivery date 1	Nature 2	Dissemination level 3
1	Questionair	6	O	PU
2	Summary of state of knowledge	24	R	PU
3	Bell systems for investigation	3	D	PU
4	Material specimens	9	D	PU
5	Procedure for the instrumentation of bells	6	R	RE
6	Instrumented bells	9	D	PU
7	Comparative presentation of the analysed data of bells under investigation	18	R	RE
8	Input data sets for simulation	6	O	RU
9	Parameterized dynamic bell system model	12	O	PU
10	Influence of parameters on contact intensity	18	R	CO
11	Demonstration of models on famous bells	24	D	PU
12	Modeling techniques for local wear and stress conditions	12	O	PU
13	Data set about the parameter influence on the wear	22	R	CO
14	Test conditions for accelerated wear testing	12	O	PU
15	Actual wear and damage progress data on bells	22	R	PU
16	Wear and damage progress data on specimens	22	R	PU
17	Guideline for the bell expert for the evaluation of the ringing	24	R / O	RE
18	Evaluation of ringing situation on 3 historical bells	24	R	PU
19	Publication of research and findings for technicians and amateurs	24	R	PU
20	Reports to the EC, Documentation	12 / 24	R	RE
21	Plan for using and disseminating knowledge Version 1	12	R	PP
22	Plan for using and disseminating knowledge Version 2	24	R	PP
23	Summary of the project to be published	1/ 12 / 24	R	PU

4.3 Activities, Achievements and Deliverables

Workpackage 1: Collection and harmonization of **field experience**
In this work package, which was continued during the whole project, the experts of the bell foundries and the bell authority were requested to provide information describing their observations in the field during ongoing bell inspections in each country.

The BellExpert as representative of the Erzbistums Freiburg and President of the German bell experts (Beratungsausschusses für das Deutsche Glockenwesen), which is an ekumenic gremium of the German conference of bishops and the Evangelic Church takes responsibility for WP1. His main task is, to consult the partners with is expertise on existing problems with bells on towers, so that finally the achievements of the PROBELL project will be practicable in the day to day work on the towers.

Initially an extensive questionair was established for a systematic description of the different damages, cracks and wear on bells. Numerous bells were visited and evaluated by the bell Expert in the last years. For the project, selected bells with known damages were visited and evaluated for the catalogue of causes for their damages. Especially a close contact with the unique welding workshop for welding damaged, weared and cracked bells, the company Lachenmeyer GmbH in Nördlingen Germany was established. In this work shop a long lasting experience with the repair of damages on bells from over Europe exists. Respectively an overview on the observed damages on bells , their causes and their repair was worked out by the project partner BellExpert Mr. Kramer together with the Mr. Lachenmeyer, the expert in repair of bells. The report was presented as an intermediate report during the Midterm Meeting on Oct. 16 and 17. 2005 to the project partners and is distributed to the partners as a document on the private area of www.probell.net

Deliverables 1 and 2 summarized in technical Report:
“TRep OTH10-1-Damages on bells and their restauration.pdf”

Workpackage 2: Materials for investigation
Measurements and investigations on the wear and damage of bells and clappers were performed directly on the bell-clapper-belfry systems. Therefore 21 bells with weights between about 180kg and 2500kg were provided to the laboratories of University of Kempten for investigations. 12 of these bells were specially cast for the project, some with inscriptions for the success of the project, see Fig. 2:

During the casting and the subsequent cooling down of the bells the temperature of the bronze was monitored by thermocouples and respective data loggers, e.g. Fig. 3. These temperature curves during the cooling process describe the metallurgical condition of the bell bronze. Their comparison for small and large bells, for different forming and mould technologies at the different foundries will allow to evaluate the importance of well defined parameters during the production of the bell for each partner in comparison to the others. The temperatures were measured in 3 locations of the bell, the most interesting sound burp and the thinnest profile area- Fig. 5. The casting is done in the individual foundries in different mould and cast technologies e.g. Fig. 4. The recorded temperature time histories and the determined gradients were presented for each bell in diagrams and summarizing numbers e.g. Fig. 6.
Additionally to this characterisation of the material of the bells, a metallographic investigation was performed by the partner TUEV-SUED. With a non-destructive technology the microstructure of the bells under investigation were documented to be evaluated in view of different mould and cast technologies. An example of such investigations is shown for one bell in one location in Fig. 7.

Fig. 2: Rincker false bell for 1to PROBELL bell with inscription:
Cognitioni sonare volo – I want to ring for the knowledge

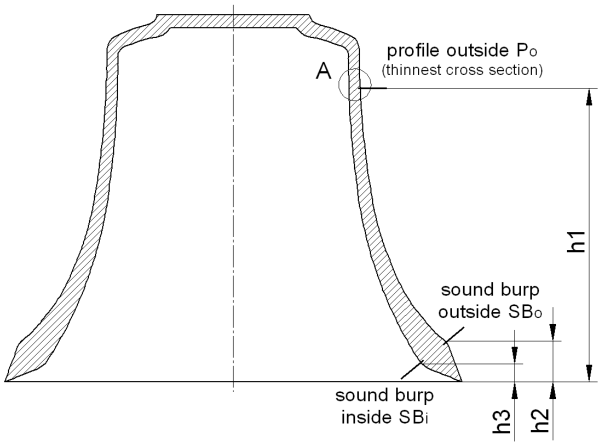


Fig. 3: Location of thermo couples

Fig. 4 Casting of bells for PROBELL Rüetschi and Cornille Havard

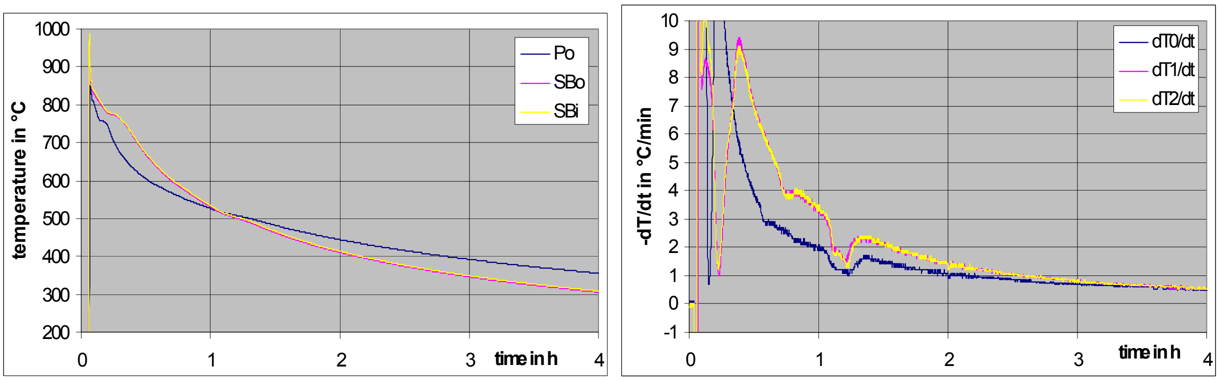


Fig. 5: Example of cooling down temperature and temperature gradient, first 4h

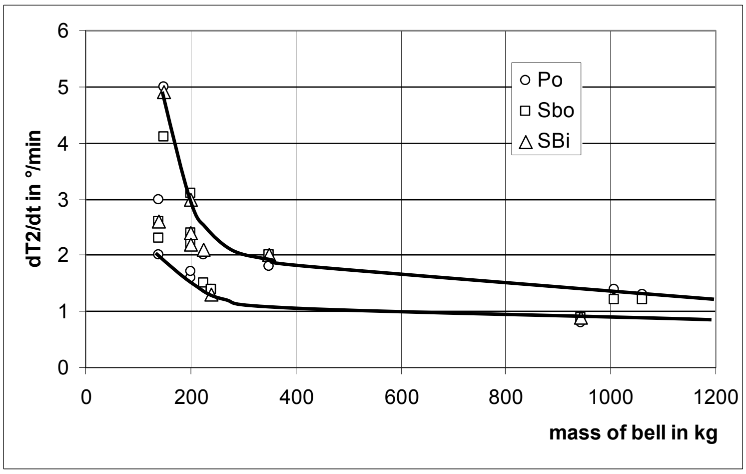
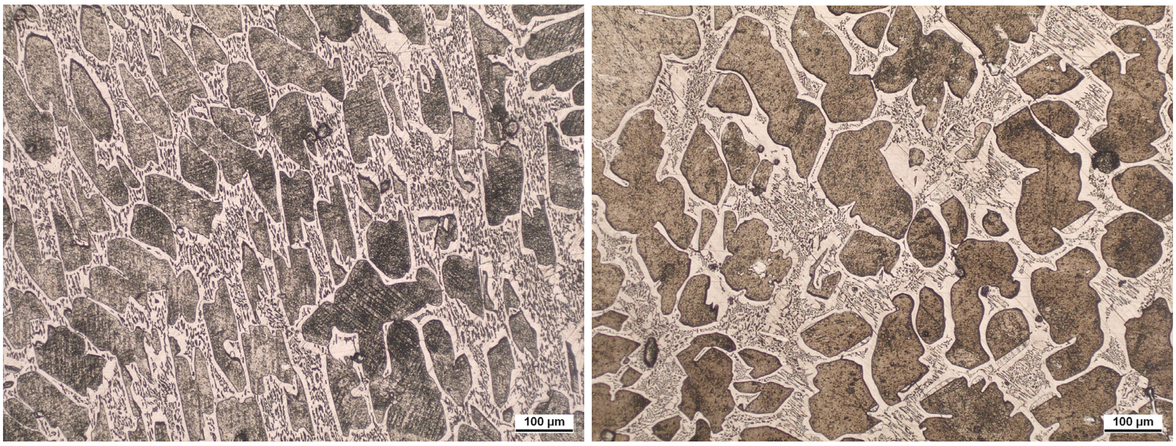


Fig. 6: Comparison of temperature gradients after second micro-structural phase change of PROBELL bells versus their weight at the sound burp and the thinnest profile



Sound burp inside   Sound burp outside

Fig. 7: Example of non-destructively obtained microstructure of a 1to bell

In Tab. 2 the delivered 21 bells with their weights, 12 of them specially cast for the PROBELL-project are listed together the provided belfries set up in the Kempten laboratory. Some of them are shown in Fig. 6. For all bells 35 clappers were provided by the clapper manufacturer and by the foundries with different shape and from different materials, on which additional variations were realised by extra weights and cutting..

Additionally, material specimens were provided for a specially developed test, the cylinder to block test for the verification of the local computer models and for the long term wear tests. Also impact and fatigue test specimens were manufactured by the partners to be tested in Kempten and Padua University.

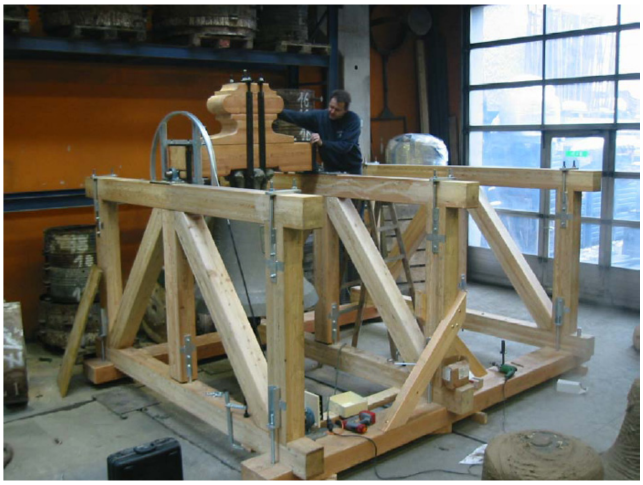


Fig. 8: Construction of PROBELL belfry for bells with 1to and 2,5to weight at Grassmayr

Fig. 9: Forging of PROBELL clappers at Rosswag

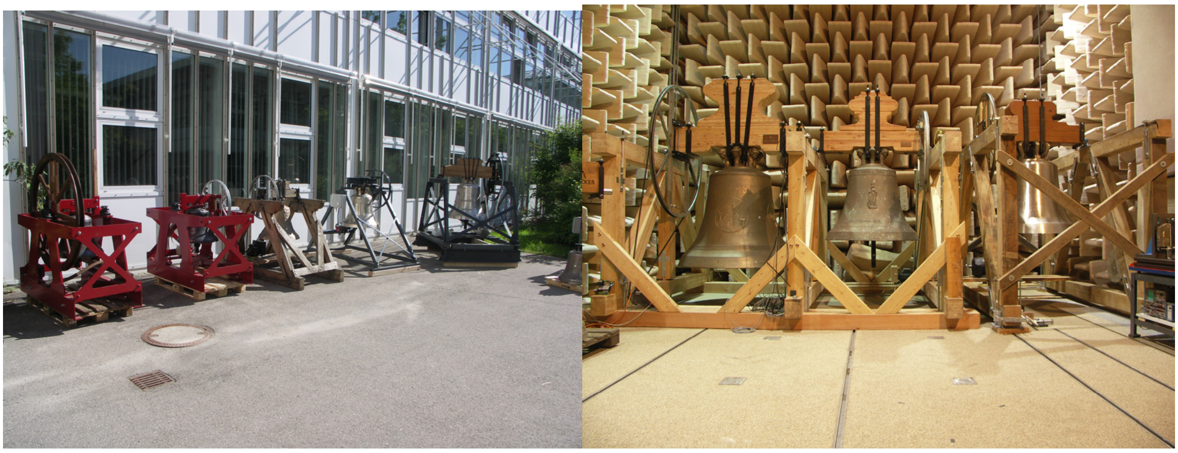


Fig. 10: some of bells at Kempten University

Tab2. Delivered bells, clappers and belfries for investigation

	Name of bell	weight in kg	belfry	clapper		clappers
Bachert	b1-1	1059	x		Rosswag	c9-1
	b1-2	1008		c1-1		c9-2
	b1-3	231		c1-2		c9-3
						c9-4
Colbacchini	b2-1	224	x	c2-1		c9-5
						c9-6
Cornille Havard	b3-1	395	x	c3-1		c9-7
						c9-8
Greassmayr	b4-1	184		c4-1		c9-9
	b4-2	352		c4-2		c9-10
	b4-3	352	x	c4-3		
	b4-4	352		c4-4		
	b4-5	2470	x	c10-1		
	b4-6	1106	x			
John Taylor	b5-1	261	x	b5-1		
	b5-2	261	x	b5-2		
				b5-3		
				b5-4		
Quintana	b6-1	212		c6-1		
	b6-2	212		c6-2		
				c6-3		
Rincker	b7-1	121		c7-1		
	b7-2	149	x	c7-2		
	b7-3	126		c7-3		
	b7-4	943				
Rüetschi	b8-1	295	x	c8-1		
	b8-2	981		c8-1		
				c8-5		

Todays computer technology provide new methods for an optimised production of cast products by cast simulation. Within the project PROBELL the foundry Cornille Havard applied modern cast simulation tools on the bell manufacturing to especially investigate the influence of casting the bell upside down in the mould. All other foundries produce bells set upwards in the mould. The 2 principles lead to very different filling situations of the mould by the bronze and completely different situations of solidification of the material. This technology was considered as advantageous but is widely unknown especially for large bells. One major drawback for the introduction of such a modern engineering technology for the bell cast is that there are no material data available for the bronze and especially for the clay.
In the past years, Cornille-Havard bell foundry changed its manufacturing technology:
to improve quality material and upside down casting in order to improve outside bell aspect and eliminate totally shrinkage porosities through a steady filling of the mold and a well directed solidification of the bell.
These changes had been achieved with very satisfactory results in terms of quality for the bells we have produced since. However, the manufacturing costs increased significantly and no experience on this new technology is available for bells weighting more than 4000 kg, and the larger the bell, the greater the risk. Therefore, we investigated if the simulation of filling and solidification can support the optimization of filling system and risers design, and reduce the risk for casting very large bells.
With CTIF (Centre Technique des Industries de la Fonderie) a well experienced sub contractor was included by Cornille Havard in a bilateral project in parallel to PROBELL to perform simulation of filling and solidification of bells in order to predict location and size of internal defects with the following objectives:

- Optimization of the metallurgical health of bells resulting from "upside down" casting in order to get the best possible quality.
- Better knowledge of properties of the bell alloy regarding the mechanical strengths and the vibrations parameters.
- Validation of casting rules of "upside down" casting, to produce in the future very large bells.
- Comparison with bells resulting from "traditional" casting.

But there is a need for accurate data that do not exist in the technical data base because the bell alloy, CuSn22, is used only for bells and therefore was never investigated before. In a first approach the necessary physical properties were elaborated by special tests for the CuSn22 alloy and data for the mould characteristics were assumed and adapted due to simulation results. Subsequently a second mid-size bell was cast as also provided for tests and measurements to UniKempten (B3-1) and was cut for many material specimens to validate the casting simulation.
CuSn22 is not a standard alloy, the thermo-hydraulic data found in data bases are not accurate enough for use in simulation in order to predict the filling and feeding behavior of a bell mould and get a realistic solidification model.
Laboratory tests were performed on actual bell material to get a first set of data then fine tune the data base comparing simulation outputs and experimental measurements.
The data required and necessary for computer simulation are :

- Temperatures of solidus and liquidus (°C)
- Latent heat (J/kg)
- Thermal conductivity ($W.m^{-1}.K^{-1}$)
- Solid fraction
- Specific heat ($J-kg^{-1}.K^{-1}$)
- Density (kg/m^3)
- Dynamic viscosity (Pa.s)

Conclusions about filling and solidification simulation
As a whole the temperature curves in the bronze obtained by simulation are relatively closed to the measured temperature curves. The data base alloy is thus validated. The defect prediction with Niyama criterion seems to give some good indications about location of possible shrinkage porosities. Correlation with experimental observation is significant

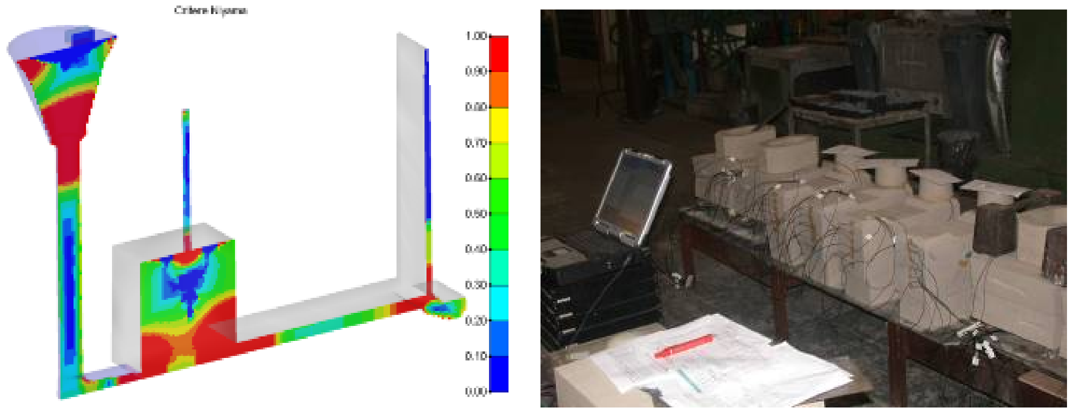


Fig. 11: Determination of material data casting and simulation of specimens

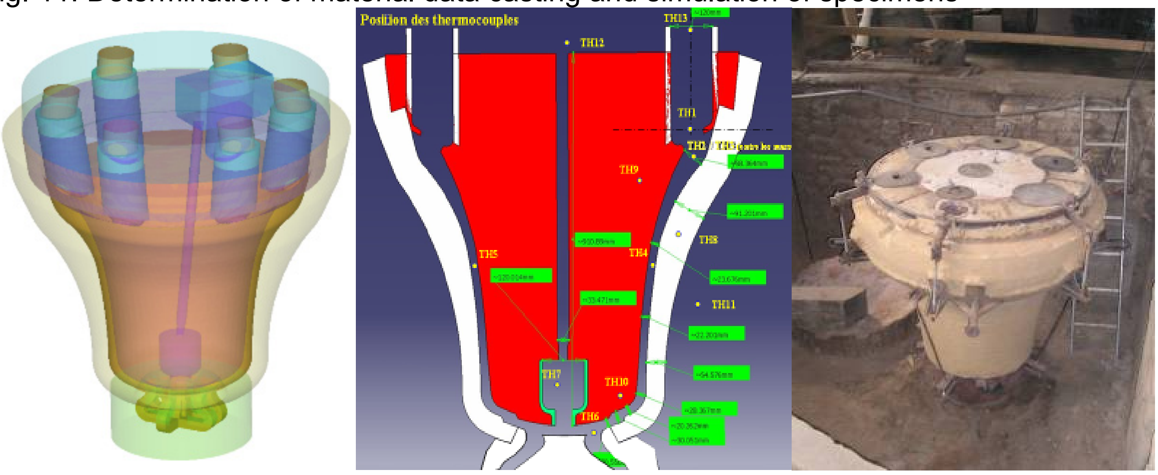
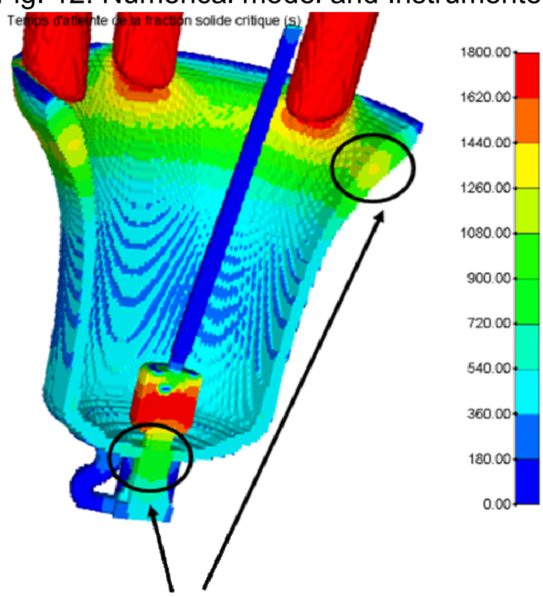


Fig. 12: Numerical model and Instrumented mould for the cast of a bell for validation



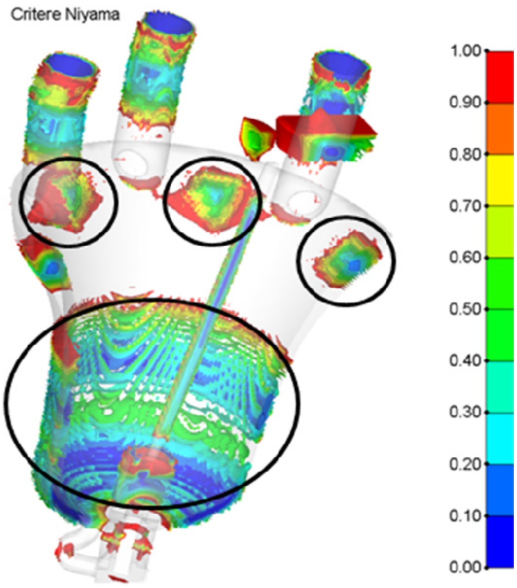


Fig. 14: Risk of shrinkage porosity: If the feeding paths cut off prematurely between the risers and the massive area.

Fig. 15: Niyama criterion: This criterion highlights the problem of feeding distance which can be at the origin of shrinkage porosities in the bell

These observations were validated by a study of feeding distance and of volume contraction. The results obtained with molding material are not totally satisfactory. An assumption to explain the difference between simulation and measurements may be:

there is an exothermic reaction in the mold.

To consolidate this assumption, we noticed that there is not a great difference between the solidification curves given by the thermocouples located in the risers and those located in the bell. With the goal of refining the results, it would be thus necessary to supplement this study with more advanced measurements on molding material.

CuSn22 data base

- A reliable data base for CnSn22 alloy was elaborated..
- These data have been specially developed for the PAM-Quikcast simulation program, but they can be used with any other simulation software.
- The simulations match the experimental data with accuracy.

Use of computer simulation

- That means that it is relevant to use digital simulation in order to improve bell manufacturing in terms of quality and costs.
- It would be a real help for optimizing the filling system and dimensioning the risers for the very large bells.

Mold material

- The molding material, made of clay and horse manure, appeared to have unexpected but useful properties.
- However, to ensure more accurate simulation, it is necessary to supplement the present study with more advanced measurements on molding material.

From Non destructive tests and structural investigations no shrinkage cavities in the bell were found. Some shrinkage porosities can be observed in non-fed areas (problem of feeding distance). The metallographic structure is in conformity with that awaited for CuSn22 alloy. The eutectoid proportion is approximately 50%. That shows either a very slow solidification or that we are in presence of reheated conditions (maybe due to clay as molding material).

From mechanical testing it can be concluded that the ultimate strength is very high, 30% to 50% higher than we know from literature. The Brinell hardness is quite high, 20% higher than we know from literature. The ultimate strength and the impact bending is 10 % lower in the areas which have some porosities.

From the computer simulation it was understood that the mould is filled completely before solidification begins. Very quiet filling with flow speed less than 0.13 m/s, except at the output of the filling system. Well directed solidification occurs. Last solidifying areas are the feeders. The feeding path do not close too early, except for the center part of the bell where some porosities are noticeable.

Future works will be:

Check the rules of feeding and filling to improve the quality and cost of mid-size bells :

- ✓ Characterization of CuSn22 alloy regarding feeding distance of the risers and volume contraction during solidification.
- ✓ Criticize Cornille-Havard methods compared to the CTIF's.
- ✓ Investigate on the molding materials in particular its water content .
- ✓ Use of computer-aided simulation tools to find easier, optimal and reliable feeding and filling system.
- Use of computer-aided simulation tools for large bells casting.
- Use of computer-aided simulation tools for traditional bell casting.
- Undertake a development to know the influence of the metallurgical quality of the cast bells regarding the mechanical and acoustical properties

Deliverable 3: 21 Bells, clappes and belfries had been delivered
(initially only 10 bells were planned for investigation)

Deliverable 4: Material specimens for testing under WP5 and WP6 are available at laboratories

Extra Deliverables **WP2** Following deliverables were not planned during preparation and proposal phase, but were only decided as useful extra investigation during kick-off and subsequent scientific committee meetings.

1. TReport RTD12-5_250906_Cooling down process of bells.pdf
2. TReport OTH11-1 Metallurgical qualification of PROBELL bells.pdf
3. CD with images of microstructure of the bells under investigation
4. D3-SME3-Cast Simulation.ppt

Workpackage 3: Instrumentation and measurements

In period 2 finally all bells with several clappers and belfries provided by the partners were instrumented for measurements to describe the dynamic system and the local and global stress conditions as well as to determine the intensity of the clapper-bell impact taking into account the different European ringing cultures. Additionally microphone measurements determined the sound of the bell and its change due to the parameters of investigations. The data are used on the one side as input for the computer simulation and on the other side for the verification of the simulation results. The respective methods and measured data are presented in

A bell in service is continuously hit by the clapper. The intensity of the clapper impact is a parameter varying statistically and at the same time is determined by the set of parameters of the dynamic system. Accelerometers (Fig. 11) have been bonded to the clappers, to identify the intensity of the individual clapper impacts. The acceleration is introduced to gain an objective measure of the individual stroke to be compared with other strokes under different parameter sets. The impact intensities has also been subjected to statistical analysis. Additionally accelerations are measured on the bell in the vicinity of the impact, to identify the energy of vibration. Of special interest is the amplitude of vibration related to the initial deformation, analysed in the main harmonics. The clapper acceleration is the quantity describing the impact intensity. On each clapper an accelerometer was bonded in swinging direction. Due to high impact intensities over a range of +-500g (g – gravity) on most of the bells accelerometers with a measuring range of 2000g were used.

Fig. 11: Setup of accelerometer on clapper inside bell

The measured accelerations are analysed in view of:

- Average impact maximum acceleration
- Standard deviation of impact max. acceleration
- Impact time as time pos. (negative) acceleration of one impact.

The standard set up for the strain measurement is shown in Fig. 12, strain gages on each side of the bell, directly opposite of the clapper impact area. The strains were measured uni-axial in the circumferential direction. The strains were directly evaluated versus material fatigue data from specimens machined out of a bell. The fatigue data were recalculated to the stress state on the sound burp.

On several bells additional strain gages were applied just above the impact area at the inside of the bell as well as over the circumference in degrees of 22,5°. Such basic information on the stress conditions inside the bell and the distribution around the bell were elaborated.

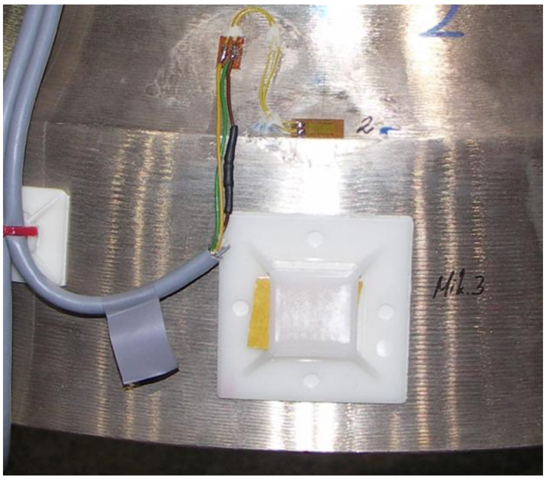


Fig. 12: Strain gages on a bell

The measured strains during 2 minutes of ringing are analysed by reading the

- maximum strain amplitude
- determination of the range pair frequency distribution
- performing a damage calculation versus the assumed Wöhler-curve of the bell with the following values: $\varepsilon_a(2*10^6) = \pm 300$ mm/m

To measure the sound of the bells, 3 microphones were installed on the bell, which are swinging with the bell. Doppler effects are not apparent. 2 microphones directly at the impact cross section give the most relevant sound connected to the impacts on sides 1 and 2. The yoke micro provides one possible sound of the bell away from the direct impact without Doppler effects, however on one side in one cross section. One microphone was set up on the ground, to provide sound data on one side of the bells, in a similar way as most measurements are performed on bells inside the towers. The micro-position was defined fix for all bells:

- twice the diameter A of the bell from the centre in one swinging direction
- on the level of the clapper ball.

The measured sound pressure data were analysed:

- FFT amplitude spectra and tone analysis
- Filtering of high and individual fundamental tones and detailed analysis

Tab. 3: Positions of microphones

microphone	position on bell
MIC 1	side 1, height bell edge
MIC 2	side 2, height bell edge
MIC Y	side 1, fixture on yoke, height cover of bell
MIC S	side 1, distance from clapper: 2x diameter of bell, height clapper ball

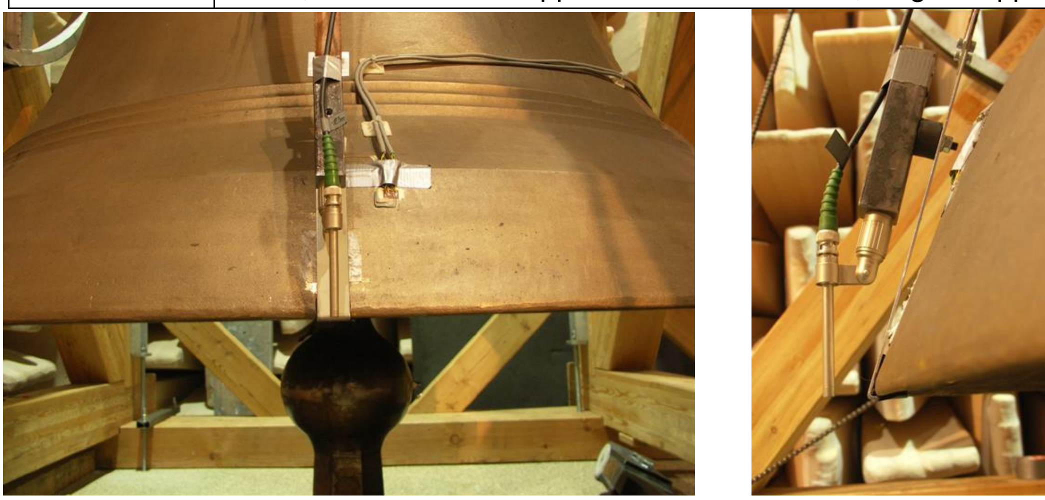


Fig. 13: Microphone (MIC 1 resp. MIC 2) in cross section of impact

Fig. 14: Microphone (MIC Y) on the yoke of bell

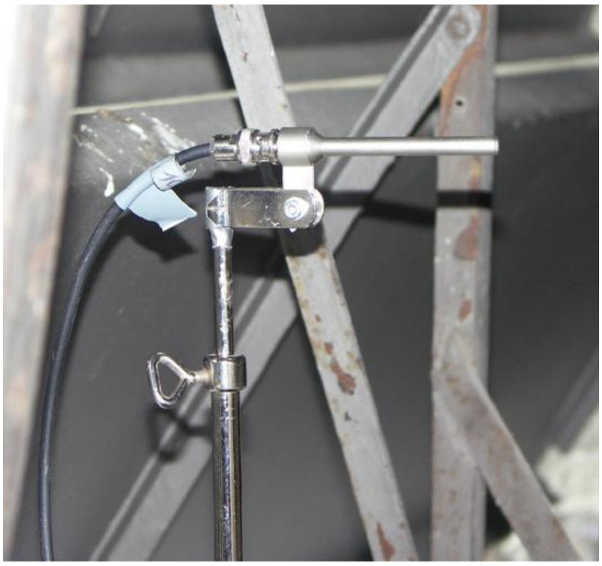


Fig. 15: Microphone on the ground 2A from the center on ball level

The ringing angle defines the usage conditions of a bell system and is strongly related to the culture of the different countries. In detail the angle is often used to adjust the dynamic system of the components bell with yoke, clapper motor in a way to achieve stabilized impact conditions and a favourable sound. On most bells it is possible to install a non contact angle sensor on the bearing of the bell according to Fig. 16.
The ringing angle is used in the analysis as reference for the evaluation of accelerations and strains.

Fig. 16: Angle sensors at the rotation axis of bells

Measurements under real ringing conditions are performed on the instrumented bell-clapper-belfry systems. Due to the statistical character of the actual stroke conditions from impact to impact, a reference ringing needs to be defined, to be able to derive reliably results which allow to determine significant influences of individual parameters. Thus a reference ringing of 2 minutes was defined for a minimum number of strokes, which allow to compare systems with different parameters by means of statistical analysis.
Parameters, set on the different bell systems are:

- Swinging angularity from ±40° to ±120°
- Clapper types with different materials, centre of impact, contact geometry
- Clapper balance by extra weight,
- clapper centricity in bell,
- Clapper guidance in the bell, concentrated contact and friction.

Strains and accelerations are recorded and analysed statistically to determine the significance of the individual parameters on local loading and stress conditions. The frequency distributions

of the local strains in terms of the range pairs are allow the fatigue damage evaluation with reference to fatigue test results available from the literature and own tests.
The clapper accelerations defining the intensity of the clapper impact are analysed statistically to define the impact for the computer simulation.

The sound pressure is analysed in a referenced way to evaluate the composition of the sound in view of the individual tones, their energy in the spectra and the damping of the individual tones. The sound pressure may be referenced to the impact energy derived from the clapper acceleration.

The measurements on the different systems with varied parameters and the respective analysis will be carried out until summer 2007, providing continuously data for the computer simulation. These activities will mainly be carried out at Uni Kempten. The evaluated interim results were presented in the Midterm meeting to the partners, to receive a feed back about the measurement and analysis procedures.

An example of measured data show the following diagrams for one bell. Note, that one measurement set on a bell with a given clapper for a set centricity of the clapper in one ringing angularity already leads to a amount of data of about 280MByte. On well bell in one set up with 5 ringing angles already about 1.4 GByte are achieved. Such amount of data must be processed and analysed automatically. Respective computer routines were developed to allow for an automated processing and analysis of the data, so that one measuring campaign on a bell needs only some days to presentation of the results.

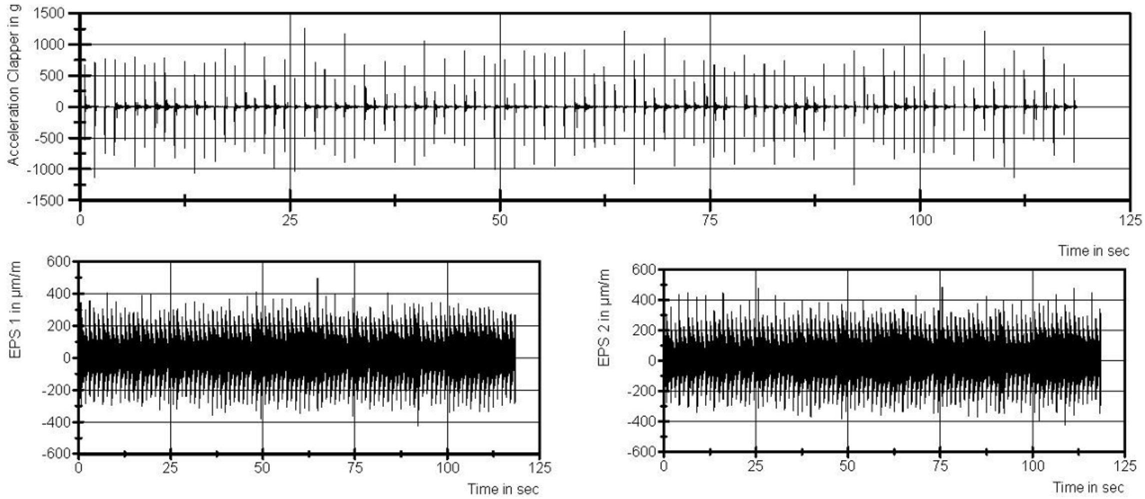


Fig. 17: Measured acceleration and strain time histories during 2min ringing

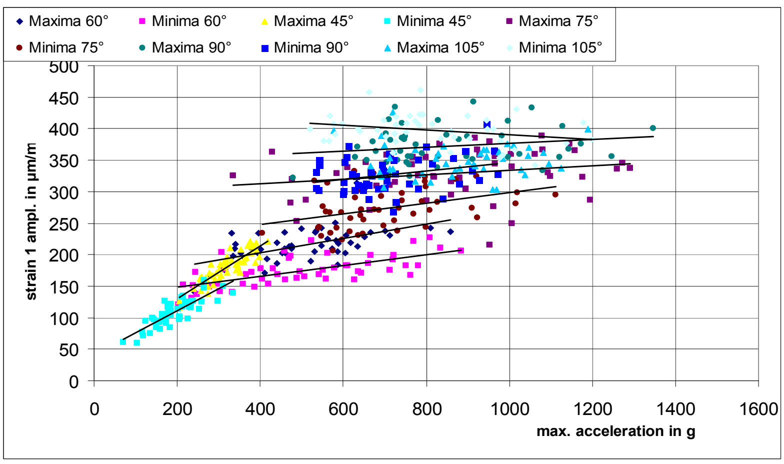


Fig. 18: Maximum strain amplitudes after each stroke versus the clapper impact intensity

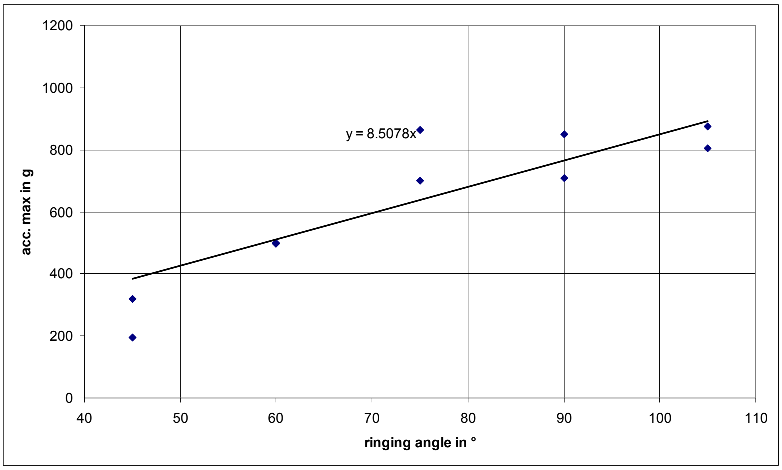


Fig. 19: Average clapper intensity versus ringing angle

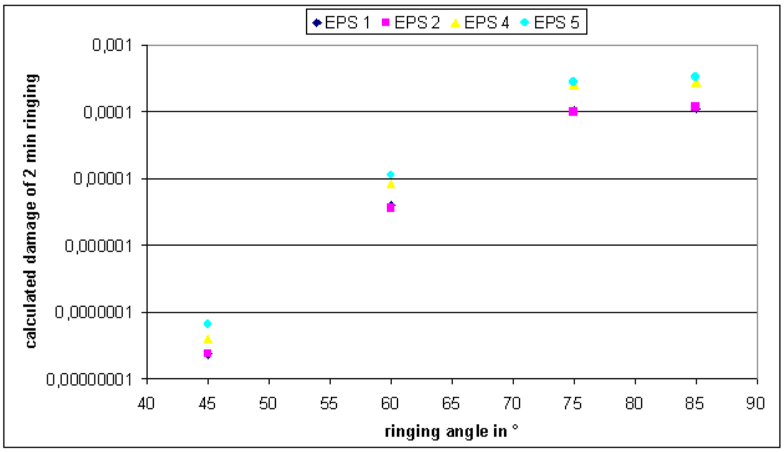


Fig. 20: Calculated damage versus ringing angle

Deliverable 5, 6, 7: D5-6-7-RTD12-measurements on bells in laboratory.doc
D7.1-RTD12-Sound Measurements and Evaluation.doc

Workpackage 4 Computer simulation of dynamic system

The aim of the project PROBELL is to investigate the parameters which determine the life of a bell and the clapper. Damages occurring on bells and clappers are the wear due to hammering in the impact area and durability of the materials. The parameters defining the damage is the intensity and frequency of the impact of the clapper. If a risk for damage is identified on a bell, only few parameters may be changed to reduce the risk of damage. Such parameters are to a certain extend the ringing angularity, the clapper parameters (shape, weight, material) and the yoke. At University AS Kempten procedures were worked out to determine the global dynamic parameters of bells and clappers. Their reliability was investigated by accurate laboratory measurements. However, such procedures can be applied by service men of the foundries on bells in the towers.

The parameters of interest on bell and clapper are as follows:

- main geometric measures
- masses
- moments of inertia
- centre of gravity
- stiffness of yoke.

These parameters determined for a bell set up, will allow to feed a computer model which should be able to simulate the actual ringing conditions in view of clapper impact and sound. In the framework of the European project PROBELL, the main aim of the University of Padova is to develop a model able to evaluate the bell-clapper motion and the impact parameters which characterise the ringing conditions, such as the impact force, impact acceleration and time

duration of the impact itself. Collecting these pieces of information is essential in order to increase the life of the bell and at the same time to guarantee its musical quality.
At University Kempten experimental procedures for the determination of the global dynamic parameters of the ringing system bell/ Clapper/ Belfry were worked out. After a detailed description of the global model, the governing differential equations based on classical Lagrange' approach and their implementation on Matlab-Simulink environment are described. Finally, several parametric analyses, based on the experimental measurements performed by the University of Kempten on Oberbueren's bell, are presented with the aim to investigate the influence of some parameters on the motion of the global model and on the impact parameters.

Global Model for Ringing Simulation
The dynamic system bell-yoke with clapper is evaluated from its components as a physical double pendulum. The motor introduces according to its control as much energy as is needed to keep the anticipated ringing angle. Dissipative energies are :

- friction in the bearings
- air resistance of bell and yoke
- sound and damping energy.

The behavior of the double pendulum cannot be described straight by formulas. Therefore a dynamic model and a respective computer simulation tool was developed to simulate the ringing conditions. According to the average clapper weight, the energy transfer during the impact was se to 95% of the dynamic energy of the approaching clapper. The program is realized under the program Matlab Simulink.

The user needs to introduce the relevant measures, which determine the dynamic behavior of the system, see above. Main results of this simulation are:

- the clapper approaching speed and its scatter,
- Ringing situation with single or multiple impacts and graphical presentation
- Period of bell
- Time and angularity of the bell phase, when the impact happens
- Bearing forces of the swinging bell system, relevant for the tower.

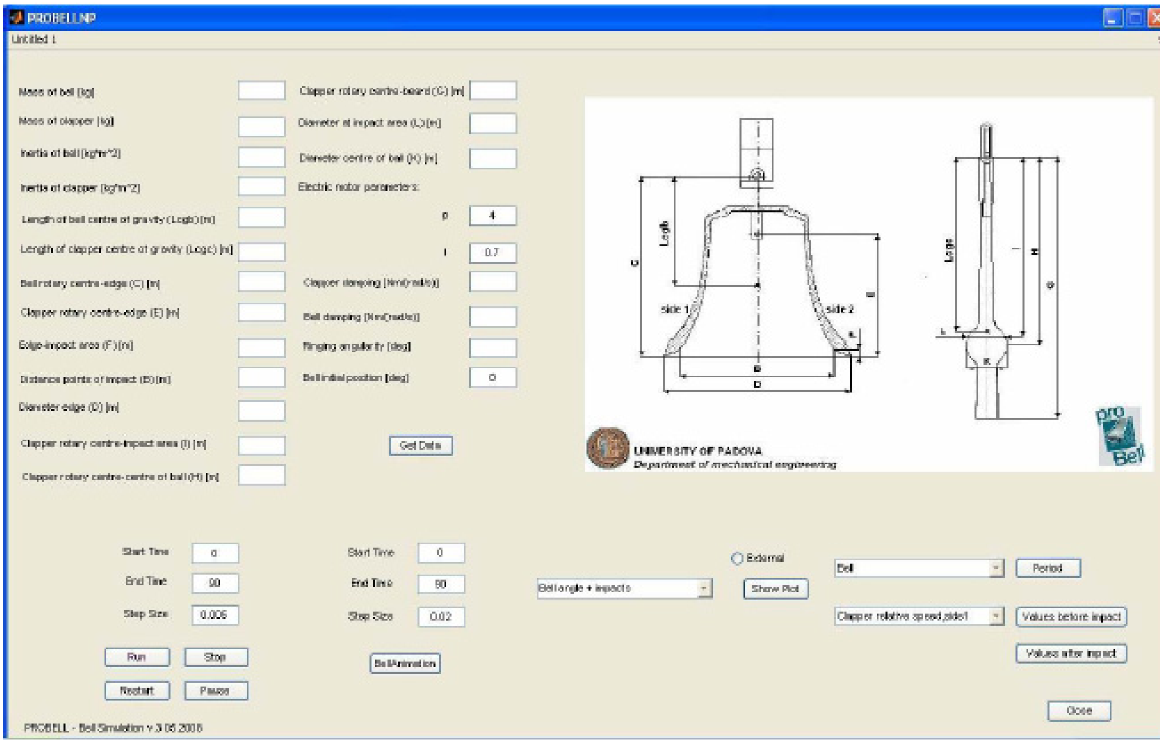


Fig. 21: Graphical user interface of the global model.

The simulation simulates 90 sec of ringing; 30 sec to stabilize the ringing conditions and 60 sec for a statistical analysis.
With the results the user can evaluate the ringing condition in view of multiple impacts, periods, approaching speed of clapper, belfry loads and uniformity of clapper impacts and thus continuous smooth ringing.

Note that the program was verified on selected bell systems and may predict the system behavior accurately. The user needs to apply the program and must verify each result to gather experience about the reliability of the tool.

The clapper impact determines the different damage phenomena wear and fatigue but also the sound of a bell. Additionally the fatigue life of the clapper and the wear of the clapper, its adaptation to the bell surface is an issue.

- With a CAD model the influence of the rotation axis of the clapper and its length are investigated. The impact point should be chosen slightly above the sound burp edge; the rotation axis should be in the crossing of the tangent to the profile at the impact and the bell axis. The flying direction of the clapper is inline with the surface normal of the bell and the clapper ball leading to a minimum in slipping and thus wear.
- The impact intensity can be described as a product of clapper mass impact acceleration and impact duration. The impact is controlled by the dynamic parameters of a given bell/yoke- clapper system and the ringing angle.
- The impact intensity determines the local wear of the bell however depending on the flying direction and the plastic deformability of the clapper and its weight.
- For the fatigue loading of the bell the parameters clapper weight and impact intensity are the determining parameters.
- The sound of the bell is depending on the impact intensity but also on the location of impact point. An optimum may be achieved when the impact is slightly above the sound burp edge. However the size of the impact area is another important parameter of the sound quality.
- The fatigue of the clapper is depending on its design and the impact intensity. The loading of the clapper is determined by highly dynamic processes, which as yet could not be described by simple engineering methods but only by sophisticated measurements and dynamic models.

Deliverable 8: “D8.1-RTD12_250708-Dynamic parameters of Bell and Clapper.doc and “D8.2-RTD12-Measures of bells and clappers.xls”
Input sets of dynamic parameters of PROBELL bells with a wide variation of ringing parameters acc. to Deliverable 7, have been continuously transferred to Uni Padua.

Deliverable 9: **D9-RTD14-Final_xxx.pdf** parameterized dynamic model of bell, clapper, belfry system available at Uni and computation results.

Deliverable 10: **D10.1-RTD12-Analysis of clapper impact.doc**
D10.2-RTD12-impact time of clapper.xls

Deliverable 11: **D11-RTD14-Global simulation of bells**.pdf

Workpackage 5: Local simulation

The experimental stress, acceleration and sound analysis for selected parameter sets on the available bell systems will provide real time data as input for the computer simulation with models of the same bell systems. These models can be verified by the measured data. Subsequently in the model parameters will be systematically changed and reliable analysis of the influence of the parameters over a wide field of parameter sets will be possible. The simulation of global and local phenomena during ringing will enable determining the influence of the individual parameters. These computer simulations will be verified by the measurements on bell systems for selected parameter sets. Subsequently the verified models will be used to calculate the influence of other parameter sets. Additionally the results of the computer modelling will be applied to design the experiments on small material specimens, on which the complex contact conditions should be realistically simulated in dynamic test rigs, and faster and simpler wear testing can be performed.

In the report the results of the local finite element simulations of repetitive clapper-to-bell impacts are presented. The local finite element simulations were performed for a bell with a mass of 308 kg, a sound burp diameter of 808 mm and a bell height (to the bottom of the bell crown) of 654 mm. A clapper mass was equal to 22 kg.
The aims of the clapper-to-bell impact simulations were the following:

- to get some insight into the impact phenomenon that occurs when clapper hits the bell;
- to enable the comparison between the results of the finite element simulations and the results of experiments.

Influences of the following nine parameters to the dynamic behaviour of the clapper and the bell were studied:

1. a clapper material,
2. a coefficient of friction between the clapper and the bell,
3. a clapper weight,
4. a clapper impact velocity,
5. a clapper hinge support,
6. a clapper impact angle,
7. a clapper radius,
8. a bell sound-burp thickness,
9. a horizontal position of the clapper-to-bell contact point.

From the results of local simulations it can be concluded the following:

- If the clapper is made from the mild steel the damage on the bell, which is measured by the residual plastic deformation, is decreased. The damage on the clapper is, on the other hand, increased.
- By using a clapper with a larger radius (a ball-like clapper) the damage on the bell and the clapper is decreased.
- If the clapper velocity is increased (by increasing the ringing angle) the damage on the bell and the clapper will increase.
- If the clapper is supported using a double-hinge support (such clapper arrangement should be typical for the Switzerland), the force impulse during the impact is slightly decreased, but the loads in the clapper fixture are decreased by 50%.
- Lighter clapper which is approaching the bell with the same velocity as the heavier clapper causes less damage to the bell, but the force impulse during the impact is also be decreased.
- For the bell it is better if the clapper is arranged in such a manner that it does not hit the bell on the smallest radius of the sound burp, but a few centimetres above this spot. However, this means that the contact point on clapper is moved towards the flyer of the clapper. If the clapper centre of gravity is above the clapper ball, the loads in the clapper shaft will increase.
- If the clapper guidance is loose, the deformed area on the bell is larger. Beside that the material of the bell in the contact zone is pressed from different directions, which additionally increases the plastic deformations of the bell in the contact zone. The clapper guidance should be as precise as possible.
- If the bell or its sound burp is made thicker, the bell is stiffer. This results in the increased damage of the bell near the contact point, but less sliding of the clapper over the clapper-to-bell contact.
- If the energy of the lighter clapper when approaching the bell is the same as the energy of the heavier clapper, the damage cause by the lighter clapper is bigger due to higher value of the contact force during the impact.

When performed the local simulations we narrowed our focus just to the local damage of the bell around the clapper-to-bell contact point. The local damage could be defined in different

ways. We measured the local damage by the residual plastic deformation, which could be easily detected on the bell (a smoothed bell surface around the contact point). If the local plastification of the bell in the contact zone is high it could even happen that some material is extracted at the border of the contact zone (two bells with such damage are mounted in the bell tower of the Benediktiner Stift in St. Lambrecht (A) and the same kind of damage was also discovered in the continuous ringing test with a hard-steel clapper at the University of Kempten). To minimise this effect the mild-steel clapper should be used.
For each clapper-to-bell arrangement we also studied sliding conditions during the clapper-to-bell contact. A Ruiz-Chen parameter, which includes the influences of the relative sliding and stresses of the material, was calculated for each arrangement. This parameter is usually applied if fretting fatigue damage could occur in the structure. No such damage in the continuous ringing tests was reported by the University of Kempten, so the Ruiz-Chen parameter could have a limited application in this case.
During the continuous ringing test at the University of Kempten it happened that a clapper broke near its hinge support. Similar clapper incidents are also reported in the practise. For this reason we calculated the bending moments at different points along the axis of the clapper shaft. Even though the bending moments in the clapper shaft near the hinge support are much lower than the bending moments in the middle of the shaft or near the clapper ball, a transition of the shaft to the flat part of the clapper is the most critical part of the clapper. Because of the thin clapper cross section the bending stresses are the highest at this point.
The report is divided into four main parts: a description of the applied finite element models, the results of the simulation, an analysis of the results, a conclusion.

Deliverable 12-13: The local model, developed and verified, is available at Uni Ljubljana and documented
D12-13-RTD13-Clapper2Bell_LocalSimulation.doc

Workpackage 6 Wear tests on bells and specimens

Considering a bell to ring about 5 min a day, the total ringing time of 1000h represents a service of about 33 years. On 8 bells long term ringing tests were performed under sever ringing conditions for more than 1000h. Such tests therefore allow to generate damages on the bells in view of wear at the impact areas and due to fatigue within a short period of about 2 months, which on the towers would occur only after some 30 years. The bells were ringing with standard clappers from mild and hard clapper steel as well as from brass alloy. The ringing angles were set to high values to generate realistic but high impact loads. Turning the bell in the yokes allowed to ring the same bell with different clappers under the same ringing condi-tions, so that the influence of the changed parameters could actually be observed. The tests were stopped each day, to measure the size of the impact areas and to maintain the ringing system. The guidance of the clapper and its damping were determined. Additionally, the tests were monitored with the standard measuring campaigns frequently during the tests. These data allow to evaluate changes of the ringing conditions, e.g. by problems with the motors or the control. The measured impact accelerations show any influence of the clapper fixture or the developing wear on the impact intensity. By measuring the local strains outside at the impact areas any change of bell loading could be identified. The sound measurements with the micros delivered the basis for the identification of changes in the sound of the bell in view of an increased contact area or initiating damages.
The most important parameters responsible for the wear of the bell at the impact areas are the clapper material respectively its yield strength. The wear volume changes with the strength of the clapper:
A clapper from a mild steel with a low yield strength (also having a rather low hardness) is cold formed by the repeated impact hammering and adapts itself to the shape of the bell. The bell therefore is deformed less and shows a low wear level.
The extreme is the use of brass allow on the clapper ball. Now deformation or wear is observed on the bell itself; all deformation and wear occurs on the clapper.
A high strength steel clapper does not deform largely but penetrates the bell with each stroke. Most of the deformation and subsequently wear happens on the bell.

However, the wear may even be more controlled by the weight, the dynamic properties of the clapper. A high strength low weight clapper may lead to less wear than a heavier mild steel clapper.
Also the clapper guidance has a major influence on the wear. A well guided clapper, hitting always on the same impact area is considered as most favourable for a low wear on the bell.
Within this report the test are documented with the developing wear which is presented as width of the impact area and the estimated wear volume. The evaluation of the results of these tests in view of fatigue and of the sound and musical quality is presented in reports D17-RTD12 ff.
During the tests multiple damages were observed on nearly all components of the bell system. These damages are reported in this report as well.

With the hell machine the local wear conditions of a clapper hitting the bell could realistically be investigated in an accelerated way. The parameters were set, so the conditions of a ringing bell of 200 to 250 kg were simulated. With the machine 25 impacts per sec could be realised, so that the number of 100 years ringing service of a bell could be simulated within a testing time of about 1 week. The difference to the real bell must be seen in the shape of the contact surface which is convex / concave on a bell and that the impact is controlled precisely in the same location during the test, whereas on a bell even with good guidance some mm of variation of the actual clapper impact may occur.
The tests were performed for high and low strength clapper steels. The results clearly indicate, that a high strength steel clapper penetrates the bell and leads to a severe local damage with on the bronze, whereas the low strength steel adapts itself to the surface geometry more and the indentation on the bell remains less deep.
During a long term ringing test the sound of the bell was recorded intermittent each 1h for the first 200h ringing and subsequently each ½ h until the end of the test for always 1 min, when a crack had occurred after 355h. The bell was set up with a heavy steel clapper of about 6,1% of the bell mass and the ringing angle was chosen with 75°, so that a stabilised impact was achieved and high loads with subsequent high stresses on the bell occurred. (Under real service conditions in a tower, the bell would be ringing with much lighter clapper.) The bronze alloy of the bell was with a rather low tin content of about 18%, which due to the higher formability leads to an increase of fatigue strength versus the standard bronze with 20 to 22° of tin.
After 355h a fatigue crack was observed under a cross section of about 70° to the impact area 2. During the continuous ringing test first changes in the sound could be heard after about 335h. During comparative listening to the recorded sound data first slight changes in the sound may have occurred already after about 322h.
The recorded sound of bell during the 355h ringing was analysed by FFT and the natural frequencies of the bell could be presented throughout the whole life. A shift and splitting of tones became visible in such diagrams after about 350h only. By analysing the intensity and damping of the impact sound it was found that the dam-ping increased continuously after 200h of ringing to about a double, however it decreased again in the final hours of service to the level before the crack.
A comparison to FEM analysis of the mode shapes of a bell with modelled crack showed a good correlation of the frequency shift and splitting, which leads to the conclusion, that with the FEM simulation it could be possible, to search for cracks in a bell, when changes in the sound were identified.
On the sound figures of the long lasting partials clearly an effect of the crack became visible, which may be described best by the smoothness of the changing intensity of these tones. With the crack, the initially observed smoothness vanished and a after about 335h a increasingly bumpy, disturbed and finally turbulent sound figure became visible.
It can be concluded, that the evaluation of the smoothness of the sound figures of the lowest partials are an important measure, to identify changes in the sound due to damages or even due to parameters not set in an optimum way.

Deliverable 14-16: D14-16-RTD12-Longterm ringing tests.doc
D14-RTD-Hell machine.doc
D16.2-RTD12-sound analysis on cracked bell.doc

Workpackage 7 Verification

Processes on a bell

The life of a bell consists of the design phase, in which the bell system with its components are planned for the anticipated tones and ringing conditions. The components of the bell system are manufactured, of which the casting process is the most important for the quality of the final musical instrument. Finally the usage conditions are set for the realized bell system by setting the ringing angle and to some extend by adjusting the motor control – see Fig. 3-1.

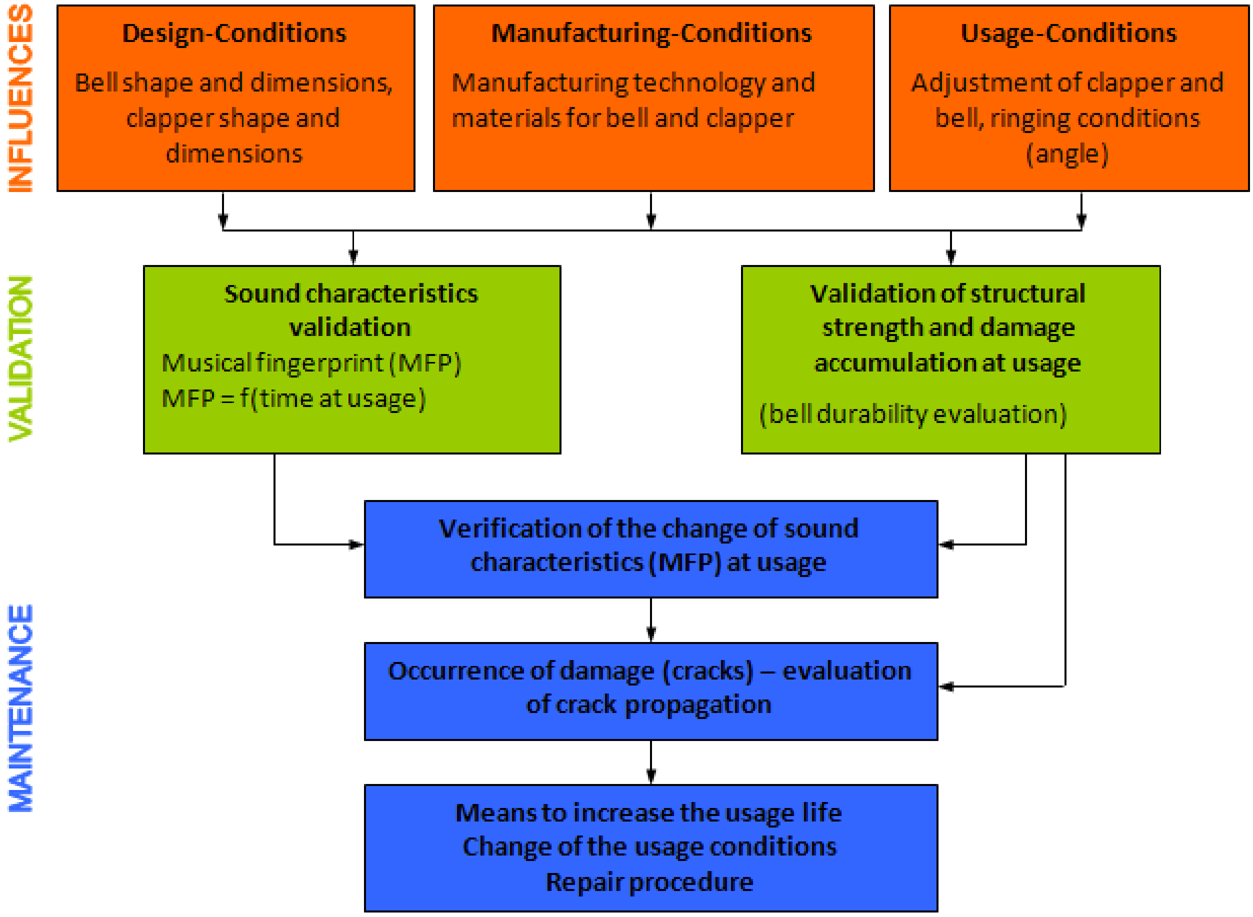


Fig. 3-1: Influences on sound characteristics and structural integrity of bells procedure for their validation (by Prof. Dr. V. Grubisic)

The design, the manufacturing and the usage conditions finally determine the life of a bell and the clapper and the musical quality of the system and are validated. However, additionally the tower and window shields are important for the musical characteristic of a set of bells in a tower, which are not considered within the project Probell. The bell system needs to be maintained to assure optimum ringing conditions providing good sound and low risk for damages. The ringing conditions can be verified by the identification of any change of the sound as a result of changes in the set up of the system, e.g. clapper fixture or drive system. Especially on old bells a change in the sound characteristic may also be caused by initiating damages by wear at the impact area or by fatigue problems. Then immediately means need to be taken, to prevent further propagation of the damages and thus to increase the life of the bell or finally repair measures.

There were no engineering tools to set up and to evaluate the components of the system bell / yoke / clapper and to adjust the ringing conditions in an adequate way for the control of the damage phenomena and the musical quality. The necessary knowledge and the respective engineering tools and data were elaborated within this project, protecting and maintaining bells in view of the criteria fatigue damage, wear at the clapper impacts and musical quality. From an engineering point of view the bell itself is considered only as part of the musical instrument "bell system" consisting of:

Bell, Yoke, Clapper, Motor and control, Ringing angle

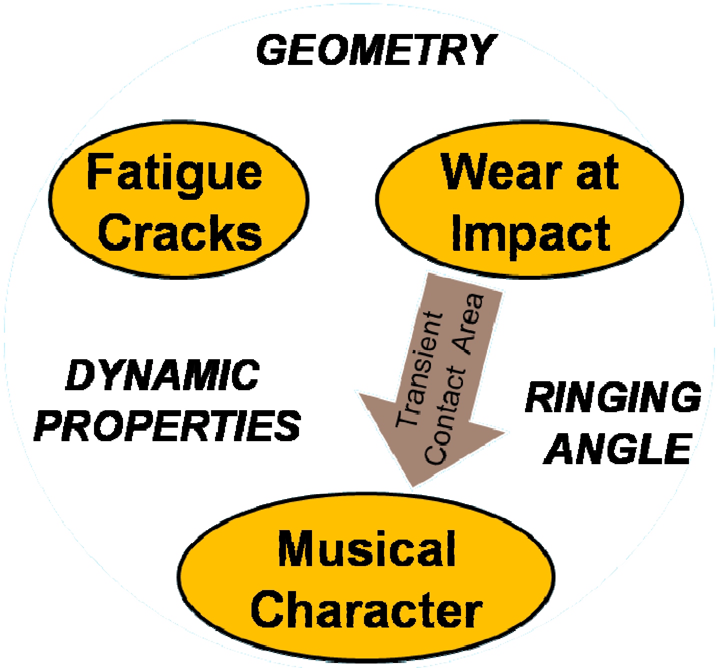


Fig. 4-1: Bell system classified in three evaluation systems

The system bell needs to be evaluated for three main objectives, the damage phenomena fatigue and wear as well as the musical characteristic. These objectives are controlled by the system parameters which consist of the geometry of the components, the parameters of the dynamic system and the ringing angle. Additionally the developing transient contact area influences the musical characteristic.

- The geometric measures of the bell and the clapper in combination with the location of the clapper fixture in the bell determines the location and the direction of the impact on the bell.
- The dynamic system is defined by the weights, moments of inertia and stiffness of bell, yoke and clapper and the relevant rotation axis of bell and clapper.
- The ringing angle set in service is the major parameter to adjust the system to most advantageous conditions for the given geometric and dynamic parameters.

If a risk for damage is identified on a bell, only few parameters may be changed to reduce the risk of damage. Such parameters are to a certain extend the ringing angularity, the clapper parameters (shape, weight, moment of inertia, material) and moment of inertia of the bell by weight on e.g. the yoke. If a damage has been developed to a certain extent, the sound of the bell changes to poor quality; then only few repair measures remain and today weared sound burps and fatigue cracks may be repaired by welding. The following figures present a systematic approach to handle the different aspects of a ringing bell system.

A new bell is designed by the bell founder for the desired tons, size, decorations and inscriptions based on the experience, tradition and available tools. The mould is prepared respectively in the well experienced methodology with the specific know how of the founder. The consequent introduction of modern engineering tools like CAD and in future cast simulation reduces effort and cost decisively. Even more important is that the risk for insufficiencies of the cast bell is diminished. The quality control of the surface integrity and the tones is performed right after the cleaning of the bell. Slight tuning measures may be necessary to meet the requirements of harmony.
The tuned bell is mounted with the other components of the system bell, the yoke and clapper. The yoke parameters determine the period and the tower loads and required ringing space in combination with the anticipated ringing angle. The main quantities to be set are the yoke mass and its center of gravity which finally defines the moment of inertia of the swinging bell with yoke around the realized rotation axis.

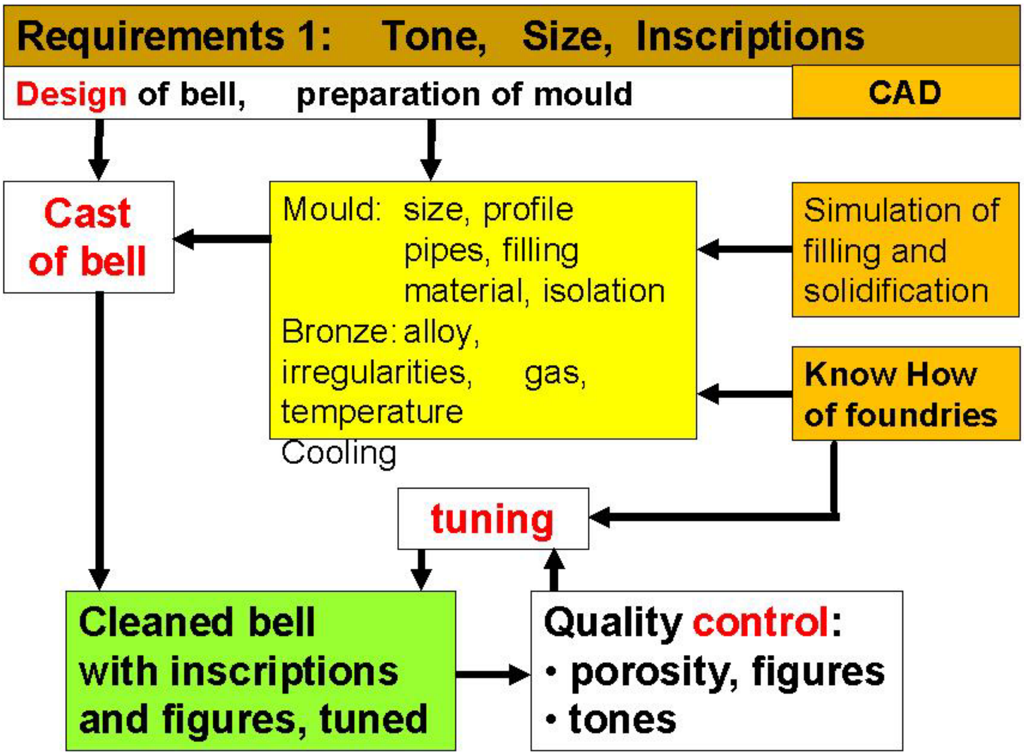


Fig. 4-2: Requirements on the bell

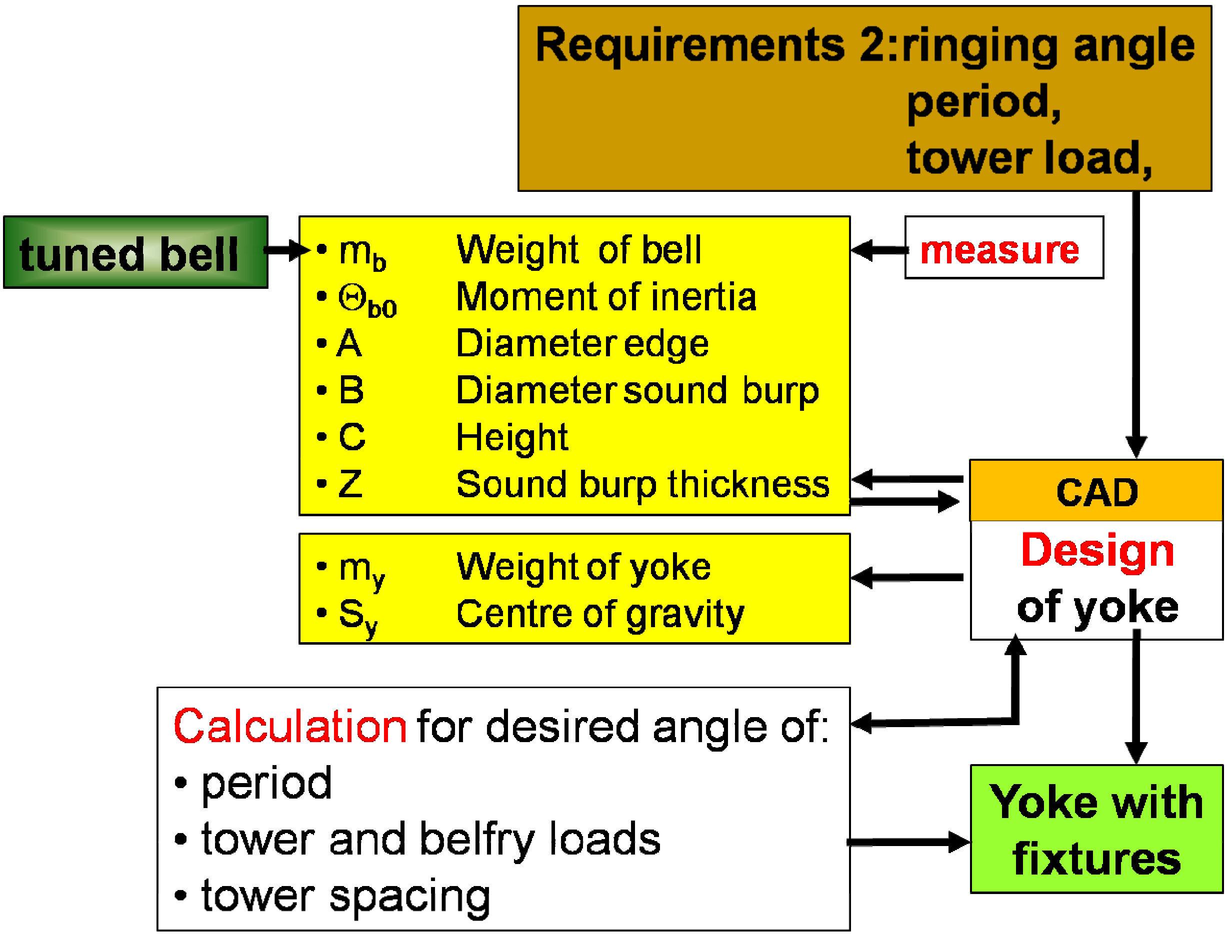


Fig. 4-3: Requirements on the bell system

The fixture of the clapper determines the concentration of the impact in one specific area and the direction of impact in the contact and the dynamic properties.
The material of the clapper is mainly responsible for the wear under continuous ringing and the transient development of the size of contact area. The shape of the clapper ball is responsible for the developing wear.
The dynamic parameters of bell and clapper are finally responsible for the ringing conditions which determine the damage phenomena and influences the sound.
Any malfunction or risk may lead to a required improvement of the system,

- the ringing angle easiest to be adapted,
- the clapper (cutting, extra weight, length) and
- if necessary the yoke e.g. by extra weight.

Low risk of fatigue damage, minimum wear and high musical quality leads to contradicting requirements on the multiple parameters. For one bell many optimum ringing conditions may be found depending on the already realized components of the bell system.
Following a summary of the conclusion of the different investigations on the bells in the project Probell is provided.
Each bell-yoke-clapper system is a unique system with its components and therefore, in many aspects no general rules may be given.

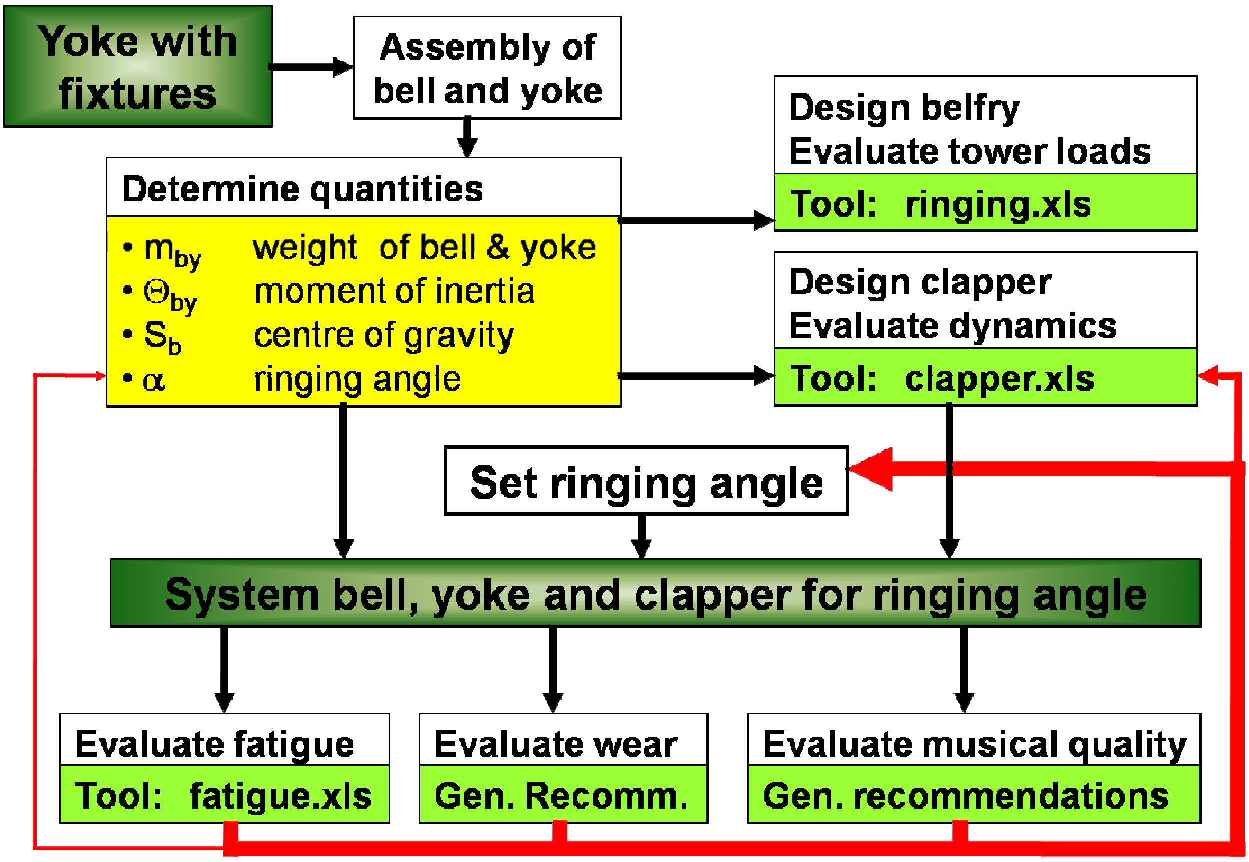


Fig. 4-4: Setup of the bell system and evaluation

The conclusions are provided in Deliverable 17 together with the elaborated working tools as Excel spread sheets.

Deliverable 16: D17-RTD12-Evaluation of bell systems.doc
D17-RT12-Bell-and-Belfry-Loads29072008.xls
D17-RTD12-Clapper-bell-system290708.xls
D17-RTD12-Impact-Life.xls

Workpackage 8 Demonstration

Within this workpackage, the procedures developed on the PROBELL bells in the laboratories are applied on bells in towers. The measured data allow to run a global model for the evaluation of the ringing conditions. The measured stresses, accelerations and the sound allow to evaluate the risc for wear and damage on such bells in the towers.
With the final results and evaluation data, this investigations allow to evaluate the actual ringing conditions of a bell and to propose improvements.

This report summarizes the methodologies to investigate bells for the evaluation of their loading situation and the resulting fatigue and wear conditions as well as to record and present the musical fingerprint of the bells under todays ringing conditions. The relevant procedures for the measurement of clapper impact accelerations, strains at the sound burp of the bell and the sound pressure were performed on 11 bells in towers, most of them famous and historical very important. The data from the bells were analysed and evaluated by the analysis tools developed within the project PROBELL. These evaluations were given to the bell foundries responsible for the bell and to the responsible persons of the domes and churches.

Tab. 0.1: Measurements on bell towers

Bell	name	location	mass in kg	description
bM-1		Oberbüren / Switzerland	3000	2 measurements cracked and after welding
bM-2	Milleniums-glocke	Hamburg / Germany	7542	cracked bell
bM-3		Oberbozen / Italy	1392	cracked bell
bM-4	Schwörglocke	Ulm / Germany	2835	bell with a clamped crack
bM-5	Pummerin	Wien / Austria	20132	
bM-7	Large bell	Bern / Switzerland	12086	
bM-8	St. Barbara	Fribourg / Switzerl.	2436	
bM-9	Savoyarde	Paris / France	18835	
bM-10	Wetterglocke	Reichenau / Germ.	2060	
bM-11	Campanone	Rom / Italy	9000	

Fig. 0-1: The investigated bells

Deliverable 18: The documentation of measurements and evaluations of all investigated bells are available in report D18-RTD12-Bells in Towers.doc.

5 Dissemination

Activities for dissemination of the PROBELL work, achievements and results already taken were:

Logo and Webside

- For the project a logo was designed by Cerny-design (www.cerny-design.de) Kempten, representing the concept of the project, investigations and tests on actual bells and sophisticated computer simulations. The logo was donated to the consortium without cost.
- A Webside was set up (www.probell.net since Dec. 2005) consisting of a public and a private area. In the public area the general information about the project is provided as well as news about the project is presented. In the private area information about the project management, minutes of meetings and reports are made accessible to the partners, who can log in with their specific password. The Webside is handled by the coordinator, but has been installed at the Karlsruher office of German Bell Experts, to ensure, that it is carefully kept even after the end of the PROBELL project. About 8000 visitors were observed on this side per week.

Press activities

During the kickoff meeting the consortium decided to include a central press representative for the project who coordinates the publications in the normal print press and television. This press agent organizes the general information about the project and its results under the control of the consortium. The BellExpert is responsible for the harmonization of such press activities. The coordinator is informed and takes care for the approval of different actions by the consortium. The press agents established a list of international interested press organs to be informed about the project and to be invited to special occasions. **Press review of the EC-project PROBELL**

2005 Press:

Date	Newspaper / Journal	Article
15.10.2005	Allgäuer Zeitung	Millionen-Projekt offiziel eingeläutet
21.12.2005	Wochenblatt	Läuten im Namen der Wissenschaft
21.12.2005	Badische Neueste Nachrichten	Zum Erhalt der Glocken
23.12.2005	Boulevard Baden	Glocken sollen schonend Läuten

2006 Press:

Date	Newspaper / Journal	Article
01.01.2006	Kirche aktuell	1,6 Millionen Euro für EU-Glocken-Forschungsprojekt „Probell“
01.01.2006	top schwaben	Der perfekte Glockenkuss
25.01.2006	St. Galler Tagblatt	135-jährige Glocke geht in Reparatur
15.02.2006	Süddeutsche Zeitung	Läuten für die Forschung
19.02.2006	Evangelische Sonntags-Zeitung	Die Suche nach dem reinen Klang
08.06.2006	Reformierte Nachrichten	Forschungsprojekt zum Thema Kirchenglocken
10.06.2006	Süddeutsche Zeitung	Von Glocken und Klöppeln
10.06.2006	Allgäuer Zeitung	Der Klöppel-Kuss – kein Dauerbrenner
14.06.2006	Badische Neueste Nachrichten	Wenn’s schräg vom Rathaus herunter klingt
19.06.2006	Südwestdeutsche Zeitung	Das Problem mit dem unsanften Eisenklöppel
Sept. 2006	Guss im Wandel der Zeit	FH Kempten erforscht Haltbarkeit von Kirchenglocken

06.09.2006	Die Rheinpfalz	Glockenforschung sucht nach dem reinen Wohlklang
09.10.2006	Katholische Internationale Presseagentur	Schweizer Giesserei liefert Testglocken für Forschungsprojekt
11.11.2006	Südwest-Presse	Der Schwörglocke droht der Gesichtsverlust

TV:

Date	Channel	Broadcast	Title
02.09.2006	BR 3	Zwischen Spessart und Karwendel	
03.12.2006	ARD	W wie Wissen	Wem die Stunde schlägt
07.12.2006	SWR	Odysso – Wissen entdecken	Glockenforschung in Kempten - Wem die Glocke schlägt
13.12.2006	RBB	Ozon	Klöppel und Klang – Warum Glocken zerspringen
19.12.2006	3sat	nano	Das Glockenlabor im Allgäu sucht nach dem guten Ton
21.12.2006	SF 1	Menschen Technik Wissenschaft	Läuten – bis zum Bruch

Radio:

Date	Channel	Broadcast	Title
14.06.2006	Deutschlandradio	Forschung aktuell	Damit Europas Glocken länger schlagen

2007 Press:

Date	Newspaper / Journal	Article
16.01.2007	EKD Ev. Kirche Deutschland	Vor Missklängen geschützt
Feb. 2007	a+o	Europäische Studie: Wie lange halten Kirchenglocken?
08.03.2007	Die Zeit	Der verschollene Klang
09.03.2007	Südwestpresse	Pro Bell wartet auf die Schwörglocke
17.03.2007	Südwestpresse	Pro Bell prüft die Schwörglocke
17.03.2007	Dolomiten	Deutschlands Glocken geben Geist auf
01.04.2007	TÜV SÜD Journal	Die Struktur macht die Musik
01.04.2007	Giessereiforschung	European research project is deciphering fundamental causes of damage in bells
03.04.2007	Berliner Morgenpost	Deutschlands Glocken sind in Gefahr
03.04.2007	Die Welt	In der Seele der Deutschen sehr tief verwurzelt
19.04.2007	Kurier	Belastungstest für Wiener Pummerin
19.04.2007	Salzburger Nachrichten	Die Pummerin als Patientin
23.04.2007	Die Presse (APA)	Sonderläuten der Wiener Pummerin
29.04.2007	Die Südostschweiz am Sonntag	Intensivforschung am „Glockenkuss“
30.04.2007	Reuters	How long will a bell bong?
01.05.2007	Giesserei	Schadensursachen bei Glocken

		gesucht
05.05.2007	Südwestpresse	Schwörglocke auf dem Prüfstand
07.05.2007	Allgäuer Zeitung	Glocken-Experten unter einen Hut gebracht
14.06.2007	General-Anzeiger	Netzwerke und Marktposition stärken
28.06.2007	Sonntag	Forschen am Glockenkuss
28.06.2007	Leben & Glauben	Forschen am Glockenkuss
31.07.2007	Aargauer Zeitung	KMU sind ein wichtiger Motor für Innovation
15.08.2007	Der Bund	Musikalischer Fingerabdruck
17.08.2007	Freiburger Nachrichten	Die Wissenschaft der Glocken
03.11.2007	www.klassik.com	Forscher untersuchen den Zustand von Kirchenglocken
Dez. 2007	Lausitzer Rundschau	Deutsche Forscher untersuchen Frankreichs größte Glocke in Sacré Coeur
01.12.2007	GEO	Kling, Glocke, spring
05.12.2007	Rheinpfalz	Der „Herzschlag“ der Pummerin
19.12.2007	EPV – Evangelischer Presseverband für Bayern	Dauerläuten bis die Glocke bricht
21.12.2007	VDI nachrichten	Läuten bis der Klöppelkuss die Glocke sprengt
24.12.2007	Allgäuer Zeitung	Auf der Suche nach dem richtigen Klang

TV:

Date	Channel	Broadcast	Broadcast
01.02.2007	3sat	nano	Forschungsprojekt "Probell" spürt Glockenschäden auf
02.04.2007	ORF	Newton	Rettung für Kirchenglocken
23.04.2007	ORF	ZiB, Wien Heute, Heute in Österreich	Aktuelle Nachricht über Messungen an der Pummerin
15.05.2007	ARTE	Gesichter Europas	Die Glockengießerfamilie aus Innsbruck
18.09.2007	SF 1	Schweiz aktuell	Kirchenglocken-Forschung
20.12.2007	BR 3	Faszination Wissen	Glockenforschung
21.12.2007	WDR, SWR, BR-alpha	Planet Wissen	Kirchenglocken – Himmlische Töne aus Menschenhand

Radio:

Date	Channel	Broadcast	Title
23.04.2007	Ö3, Ö-Reginal	Nachrichten (stündlich)	Aktuelle Meldungen über Messungen an der Pummerin
23.04.2007	Antenne, Life Radio	Nachrichten (stündlich)	Aktuelle Meldungen über Messungen an der Pummerin
05.06.2007	Ö1	Dimensionen – die Welt der Wissenschaft	
21.12.2007	Bayern 2	IQ – Wissenschaft und Forschung	

Internet:

Date	Page	Title
03.05.2007	http://edition.cnn.com/2007/WORLD/ europe/04/30/bells.reut/index.html	How long will a bell bong?

2008 Press:

Date	Newspaper / Journal	Article
13.01.2008	Sonntagsblatt Bayern	Dauerläuten gegen den Mißklang
18.01.2008	Bayerische Staatszeitung	Schlagen bis zum Tod
01.02.2008	MP Materials Testing	Kirchenglocken – Kulturgut, Musikinstrumente und hochbeanspruchte Komponenten
02.02.2008	Der Spiegel	Akustik: Plok statt Gong
28.02.2008	Deutsche HandwerksZeitung	Glockensterben im schalltoten Raum
17.04.2008	ANSA	Check-up per campanone di S.Pietro, in buona salute
18.04.2008	Il Messaggero	Check up per il Campanone: è in salute
08.05.2008	Allgäuer Zeitung	Allgäuer steigen dem Papst aufs Dach
01.07.2008	Giesserei	Check-up der größten Glocke im Petersdom

TV:

Date	Channel	Broadcast	Title
10.-16.04.2008	Euronews	Futuris	Das europäische Forschungsprojekt Probell

Radio:

Date	Channel	Broadcast	Title
14.06.2008	Deutschlandradio Kultur	Deutschland Rundfahrt	Das ungewöhnliche Forschungsprojekt

Lectures:

Date	Location	Cause	Title
30.09.2005	St. Florian, Linz	Internationale Glockentage	Verlängerung der Lebensdauer von Glocken
30.11.2007	Berlin	Bundesanstalt für Materialprüfung	Kirchenglocken – Kulturgut, Musikinstrumente und hochbeanspruchte Komponenten

Publication:

R. Spielmann, A. Rupp, M. Fajdiga, B. Atzori, Kirchenglocken – Kulturgut, Musikinstrumente und hochbeanspruchte Komponenten, in: Glocken – Lebendige Klangzeugen, Des témoins vivants et sonnants, Schriftenreihe Denkmalpflege, Heft 5, 2008 (ISSN 1660-6523)

At the moment 4 further publications for scientific symposiums are under preparation.
A lot of additional press invitations and press releases of press agent, Mrs. Knauber

The dissemination policy therefore is considered as absolutely satisfying.

6 Final Plan for Dissemination

European Competence Center for Bells

At the University of Applied Sciences Kempten, a competence center will be established, to provide expertise to parishes, churches, offices of cultural heritage and bell experts as well as to bell foundries, clapper manufacturers and motor and control providers about the questions of bells in towers.

One major issue will to develop the competence on bells for the foundries, so that they may provide services not on the bells alone, but the belfries, motors, acoustic design of bell rooms.

It is of special importance to support the partners in their work to apply the new methods in their daily work. Therefore, the responsible engineer of the project at University AS Kempten will be continuously employed at the University, to hold the special Know How available for the bell community.

The necessary resources are provided by the bell foundries and the University AS Kempten, within its general activities for Research and Cooperation. By project work, however, at least 50% of the cost for the centre are to be acquired.

Webside

The project webside www.probell.net will be continued tp provide a forum and platform to all bell interested for exchange on this matter.

The introduction of the achievements are planned as follows:

In phase 1 the guidelines as a basic for the training of service personal of the partners were elaborated in cooperation with the RTD partners during the end of the project. These findings summarized in the guidelines, were presented and discussed during a 3 day meeting in July with all partners of the project. With the summary and guidelines are documented in Delivery 17 as report and Excel spread sheets and Matlab Simulink implementation. After a period of review several actions for dissemination are planned:

Application tools

The methods and data, elaborated in the project Probell were provided to the partners as a Matlab Simulink implementation and in the form of Excel spread sheets and data table. These tools will be improved in the form of software tools, to better support the partners in the application of the new methodologies in their daily work.

Additionally the necessary working tools for the personal on the tower, will be defined and offered as a work bench to the partners. It consists of load cell, microphones, computer data acquisition and evaluation tools.

Seminars for selected personal of the partners:

An intense and detailed seminar is prepared including all details of technologies and findings, to train the responsible engineers and technicians of the partner companies.

Symposium

A symposium is planned for mid of 2009 at University AS Kempten, to which besides the partners, experts and interested people, as well as responsible persons of cultural heritage office, and churches are invited. During this seminar the findings of the project Probell are presented and discussed.

Proposals for future work are presented.

Seminars for bell experts

A special seminar for bell experts will be prepared, to introduce bell experts to the new knowledge. Some technologies and details considered as confidential by the SME partners, will not be included.

Publications and presentations on Symposiums and conferences

Publications and presentations in different magazines and on conferences are under preparation.

The Vatican announced that it would support the distribution of the new methods worldwide, by the Vatican press.

Future Projects

There are several possibilities for project of the experienced team of University Kempten in collaboration with the partner Universities in Padua and Ljubljana.

- The partners often report about problems on bells such as cracks or the introduction of new repair technologies. The University Kempten can now offer a special service as independent institution to evaluate the reasons for such problems or the risk of new technologies. Such Projects are offered as an engineering service and will help to gain resources for the European Competence centre of bells.
- Based on the methods and achievements, the Consortium will propose to all relevant institutions, the churches and the parishes, to establish an amendment to the Bell Atlas, a compendium about historical data of bells, their musical finger print. Especially for historically and culturally important bells, the musical fingerpring, recorded, analysed and presented in the way elaborated within the project, will allow in future, to identify any damages in a very early stage, and thus be able to take measures to prevent severe damages.
- New research projects may have two main objectives; the optimization of cast process to reduce production risk especially for large bells and the quality control and evaluation of repair measures e.g. welding.